



Calhoun: The NPS Institutional Archive
DSpace Repository

Theses and Dissertations

1. Thesis and Dissertation Collection, all items

1992-09

Effectiveness and cost-effectiveness evaluation of an advanced artillery weapon system

Arbel, Giora

Monterey, California. Naval Postgraduate School

<http://hdl.handle.net/10945/38564>

Copyright is reserved by the copyright owner

Downloaded from NPS Archive: Calhoun



Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

<http://www.nps.edu/library>

AD-A257 477



2

NAVAL POSTGRADUATE SCHOOL Monterey, California



S DTIC
ELECTE
NOV 27 1992
A D

THESIS

**EFFECTIVENESS AND COST-EFFECTIVENESS
EVALUATION OF AN
ADVANCED ARTILLERY WEAPON SYSTEM**

by

Giora Arbel

September 1992

Thesis Advisor:

D. C. Boger

92-30286

Approved for public release; distribution is unlimited.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS		
2a. SECURITY CLASSIFICATION AUTHORITY			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE					
4. PERFORMING ORGANIZATION REPORT NUMBER(S)			5. MONITORING ORGANIZATION REPORT NUMBER(S)		
6a. NAME OF PERFORMING ORGANIZATION Naval Postgraduate School	6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION Naval Postgraduate School			
6c. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000		7b. ADDRESS (City, State, and ZIP Code) Monterey, CA 93943-5000			
8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER			
8c. ADDRESS (City, State, and ZIP Code)		10. SOURCE OF FUNDING NUMBERS			
		PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) Effectiveness and Cost-Effectiveness Evaluation of an Advanced Artillery Weapon System					
12. PERSONAL AUTHOR(S) Giora Arbel					
13a. TYPE OF REPORT Master's Thesis	13b. TIME COVERED FROM _____ TO _____	14. DATE OF REPORT (Year, Month, Day) September 1992		15. PAGE COUNT 98	
16. SUPPLEMENTARY NOTATION The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Target Damage Assessment, Cluster Warhead, TCAR, Trajectory-Corrected Artillery Rocket, SFM, Sensor Fuzed Munitions, Artillery Rocket		
19. ABSTRACT (Continue on reverse if necessary and identify by block number) This thesis examines the role of modern artillery as a defensive as well as offensive weapon—one which is capable of destroying targets and achieving an advantage on the battlefield rather than merely performing traditional tasks of attrition. The thesis demonstrates that the new capabilities can be attained. A new concept of artillery weapon system—the Trajectory Corrected Artillery Rocket system (TCAR)—is analyzed. Results show that this new artillery system, when it contains a cluster bomblet warhead, is very effective against infantry in an open area, with destruction levels of 50 to 90 percent, but it is not sufficiently effective against fortified and armored targets. However, when this system accommodates SFM ("smart") submunitions, it proves effective against armored vehicles, with destruction levels of up to 70 percent. Simulation programs were developed which assessed damage levels on a variety of targets. A set of these targets was chosen for which a comparison analysis was made between the TCAR and two other well-known artillery systems: 155 mm gun and a free-flight artillery rocket system. Two parameters were tested: rate of kill and marginal cost. Results demonstrate the clear advantages of using TCAR over the other systems when accompanied by a cluster warhead. Furthermore, it was found that the TCAR is the currently preferred system suitable for SFM.					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT <input checked="" type="checkbox"/> UNCLASSIFIED/UNLIMITED <input type="checkbox"/> SAME AS RPT. <input type="checkbox"/> DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL Professor D. C. Boger			22b. TELEPHONE (Include Area Code) (408) 646-2607		22c. OFFICE SYMBOL

DD Form 1473, JUN 86

Previous editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

Unclassified

Approved for public release; distribution is unlimited.

**Effectiveness and Cost-Effectiveness Evaluation of an
Advanced Artillery Weapons System**

by

Giora Arbel
Chief Engineer, Israel Military Industries
B.S.C., Technion Haifa, Israel, 1977

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1992

Author:

[Redacted]

Giora Arbel

Approved by:

[Redacted]

D. C. Boger, Thesis Advisor

[Redacted]

S. H. Parry, Second Reader

[Redacted]

P. Purdue, Chairman,
Department of Operations Analysis

ABSTRACT

This thesis examines the role of modern artillery as a defensive as well as offensive weapon—one which is capable of destroying targets and achieving an advantage on the battlefield rather than merely performing traditional tasks of attrition. The thesis demonstrates that the new capabilities can be attained. A new concept of artillery weapon system—the Trajectory Corrected Artillery Rocket system (TCAR)—is analyzed. Results show that this new artillery system, when it contains a cluster bomblet warhead, is very effective against infantry in an open area, with destruction levels of 50 to 90 percent, but it is not sufficiently effective against fortified and armored targets. However, when this system accommodates SFM ("smart") submunitions, it proves effective against armored vehicles, with destruction levels of up to 70 percent. Simulation programs were developed which assessed damage levels on a variety of targets. A set of these targets was chosen for which a comparison analysis was made between the TCAR and two other well-known artillery systems: 155 mm gun and a free-flight artillery rocket system. Two parameters were tested: rate of kill and marginal cost. Results demonstrate the clear advantages of using TCAR over the other systems when accompanied by a cluster warhead. Furthermore, it was found that the TCAR is the currently preferred system suitable for SFM.

DTIC QUALITY INSPECTED 4

Accession For	
NTIS CRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By	
Distribution /	
Availability Codes	
Dist	Availability Code
A-1	Special

TABLE OF CONTENTS

I. INTRODUCTION.....	1
A. THE ROLES AND CHARACTERISTICS OF MODERN ARTILLERY	1
B. TRAJECTORY CORRECTED ARTILLERY ROCKET SYSTEM	2
1. TCAR Operation Concept.....	2
2. More-Detailed Engineering Description Restrictions	3
C. GOALS OF THIS THESIS	4
D. METHODOLOGY.....	4
E. INPUT DATA.....	5
F. SIMILAR ANALYSIS WHICH HAS BEEN PUBLISHED.....	5
II. THE MODEL AND ITS IMPLEMENTATION.....	6
A. INTEGRATION METHOD TO ASSESS DAMAGE LEVEL OF HOMOGENEOUS TARGET	6
1. Damage Assessment Model of a Homogeneous Target.....	6
2. Model Application	11
3. Program Execution Analysis.....	12

B.	SIMULATIONS OF TARGET DAMAGE ASSESSMENT FROM CLUSTER BOMBLET WARHEADS.....	12
1.	Simulation Program of Small Targets When Firing Unit Size is Not Considered.....	12
2.	Simulation Program of Small Targets When Firing Unit Size and Rate of Firing Are Considered	14
C.	SIMULATION OF TARGET DAMAGE ASSESSMENT FROM SMART SUBMUNITION WARHEADS.....	17
D.	OTHER PROGRAMS	18
1.	Dealing With Large Targets.....	18
2.	Consecutive Statistical Calculations.....	20
E.	RUNNING THE PROGRAM.....	20
1.	Systems Data.....	20
2.	Simulation Output	26
III.	TARGET DAMAGE ASSESSMENT	27
A.	TARGET DESCRIPTIONS AND RESULTS	27
1.	Target Number 1: Uniform And Homogeneous Density—Troops.....	27
2.	Target Number 2: Troops in an Open Area, Nonsymmetrical Homogeneous Target.....	35
3.	Target Number 3: Troops in a Company at a Defense Site.....	39
4.	Target Number 4: Self-Propelled Armored Howitzer Gun Battery in Firing Deployment	41
5.	Target Number 5: Soft Vehicles, Logistic Convoy	47

6. Target Number 6: Mixed-Type Target In Defense Position.....	51
7. Target Number 7: Armor in an Offensive Site.....	56
8. Target Number 8: Artillery Weapon with SFM Submunition as an Anti-Tank Weapon	57
IV. CONCLUSIONS AND RECOMMENDATIONS	62
A. EFFECTIVENESS AND MARGINAL COST.....	62
B. ACCURACY	62
C. RECOMMENDATIONS.....	63
APPENDIX A NUMERICAL INTEGRATION OF THE PROBABIL- ITY DENSITY FUNCTION OVER AN HOMOGEN- EOUS TARGET AREA-- PROGRAM CODE.....	64
APPENDIX B TARGET DAMAGE ASSESSMENT, SIMULATION PROGRAMS CODE.....	67
LIST OF REFERENCES	90
INITIAL DISTRIBUTION LIST.....	91

I. INTRODUCTION

A. THE ROLES AND CHARACTERISTICS OF MODERN ARTILLERY

Artillery weapons were never considered main actors on the battlefield or a destructive force with a unique mission. The conventional theory of the role that artillery plays on the battlefield is that it is a weapon which supports assault and defense forces—it acts as an attrition and suppression weapon assisting main forces. Another important facet of the nature of artillery weapons, according to this convention, is that they cover area targets (as opposed to pinpoint-accurate antitank weapons).

However, a modern view is that artillery weapons, in addition to their conventional tasks, also act as main forces with unique missions. In addition, they have accurate singular destructive capabilities. This new concept permits the use of artillery for the following missions:

- Breaking massive assault forces of superior numbers, and
- Attacking high-priority long-range targets.

Modern artillery is characterized as:

- Capable of massive fire power operating in small units
- Long-range (more than 30 km)
- Destructive capability for a variety of targets (including "hard" targets)
- High survivability of launching units on the battlefield

Newly developed artillery rocket systems were expected to achieve all the above requirements, and they are indeed effective. Due to their low accuracy, however, they were found not to be cost-effective weapons.

Newly developed artillery rocket systems were expected to achieve all the above requirements, and they are indeed effective. Due to their low accuracy, however, they were found not to be cost-effective weapons.

B. TRAJECTORY CORRECTED ARTILLERY ROCKET SYSTEM

The Trajectory Corrected Artillery Rocket system (TCAR) is a new concept of an artillery weapon which is in a feasibility study stage at the Israel Military Industries (IMI) Ltd. TCAR could be defined as a semi-guided missile, but we have chosen not to call it such because this family of weapons system has an entirely different structure and purpose. The system has all the advantages of the modern artillery rocket systems, as mentioned above. By controlling the rocket trajectory, accuracy is substantially enhanced. As a result, force effectiveness and system cost-effectiveness may be significantly improved.

1. TCAR Operation Concept

A rocket equipped with only a simple steering mechanism is fired from a launcher. A ground station, located near the launcher, tracks the rocket trajectory. At a certain point along the trajectory, the ground station computer simulates the expected hit points based on the data gathered from this tracking and compares them to the target location. A correction command is sent to the rocket, which then performs the correction. The tracking system process continues in a closed loop until the rocket disappears from line of sight.

The TCAR is neither a pinpoint-accurate missile nor an inexpensive free-flight ballistic weapon—it stands between those two categories. The addition of an inexpensive (but not perfectly accurate)

guidance facility to the free-flight rocket increases the unit cost, but the cost is still significantly less than that of a missile. Therefore, the TCAR is capable of being employed extensively as an artillery weapon.

This thesis evaluates the Trajectory Corrected Artillery Rocket system's effectiveness and cost-effectiveness as compared to two other artillery systems:

- Extended range howitzer guns
- Modern free-flight rocket systems.

An extended-range howitzer gun is called a Rocket Assisted Projectile (RAP) or Base Bleed (BB). Modern free-flight rocket systems are currently being used in the US as MLRS and in Israel as LAR160.

Two types of warheads will be discussed:

- Cluster warhead with antipersonnel/antiarmor (ap/am) scatterable bomblets
- "Smart" warheads which contain scatterable "sense and destroy" antiarmor/antitank submunitions (This thesis text uses the alternative name, Sensor Fuzed Munitions [SFM].)

Models of some typical terrain targets were chosen on which troops, artillery, armored personnel carriers and tanks were located.

2. More-Detailed Engineering Description Restrictions

The TCAR concept already exists in the form of an Israeli classified system, so a complete description of that system is not possible here and the engineering details cannot be discussed. However, performance data relevant to a generic TCAR system will be used in the models of this thesis.

C. GOALS OF THIS THESIS

The goal of this thesis is to generate quantitative data that will be used by the system's developer to assess cost-effectiveness in the acquisition of the new system by potential customers (armies). Main points to be included are:

1. The effectiveness which is achieved when artillery rocket system accuracy is enhanced, and
2. A comparison of the cost-effectiveness of competitive artillery weapons in order to test the feasibility of this new concept.

It is not within the scope of this thesis to carry out a full combat deployment analysis of each weapon system.

D. METHODOLOGY

The work includes building simulation programs that will accept, as input, all the parameters of those random factors affecting the performance of each system. This will result in an evaluation of the effectiveness of each system on the specific target models.

The simulation results will determine the number of rounds for each system that must to be fired in order to achieve various target damage criteria. Cost-effectiveness (i.e., cost per target destruction level) is calculated accordingly.

The following additional factors will be considered:

- Rate of fire
- Size of the firing units
- Survivability of the firing units

E. INPUT DATA

The particular systems on which the simulation will be performed for comparison with the TCAR are:

- G155— 155 mm howitzer gun, using as ammunition the RAP (Rocket Assisted Projectile)
- MARS (Multipurpose Artillery Rocket System)—based on the rocket system LAR160 (or its derivatives) that was developed and is currently produced by the IMI, Ltd.

All the data necessary for the simulation was provided by IMI as real data. However, because the TCAR is under development, analyses must be based on continually updated data for the system as it becomes available.

F. SIMILAR ANALYSIS WHICH HAS BEEN PUBLISHED

Due to the new military applications of the systems and warheads which were analyzed, no comparable studies could be found in the open literature. IMI's Operational Analysis Department and some of the Israel Defense Forces operational research branches have done damage analysis for weapon systems that carry cluster bomblet warheads. All those analysis results were printed in Hebrew, while some of them, by nature, are classified and therefore are unavailable for this thesis. Similar military US material (even unclassified) was inaccessible because of the author's status as a foreign student in the US.

The TCAR as a weapon system is a new concept, so no published analysis could be found in the unclassified literature.

General methods of target damage assessment are described in the References 1 through 4. A description of the SADARM (Sense and Destroy Submunition) is given in Reference 5. The SFM, which is described elsewhere in this thesis, is similar.

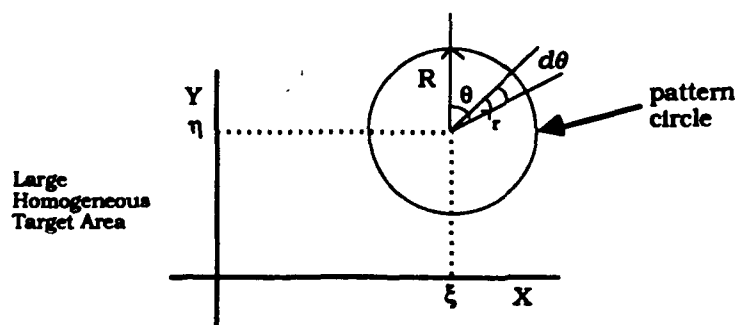
II. THE MODEL AND ITS IMPLEMENTATION

It was essential to this thesis to write a Monte Carlo simulation model in order to evaluate target damage levels for various target types using the three alternative systems. Since an area target is the simplest type to be evaluated, the results from the simulation model were checked against an exact formulation (using numerical integration) of the area target to determine the accuracy of the simulation model. Once the simulation model generated results comparable to the exact model for the area target, the simulation model was modified with several other target types and munitions types. Missions on which salvo time duration is considered a deficiency factor and targets that contained scattered armored vehicles were also included.

A. INTEGRATION METHOD TO ASSESS DAMAGE LEVEL OF HOMOGENEOUS TARGET

1. Damage Assessment Model of a Homogeneous Target

a. Lethal Area of a Single Warhead



Assume that the target area is homogeneous and infinitely large and that a single warhead bursts above target area at location (ξ, η) . The

location of a target element inside the pattern circle of radius R is described in polar coordinates by (r, θ) centered on (ξ, η) . Define $P_{K/T}[(r, \theta)/(\xi, \eta)]$ to be the probability of kill of the target element, conditioned on the target element's location as described above. Next, define f_H to be the pdf of the rocket ballistic dispersion, and therefore $f_H(\xi, \eta)$ is the probability that the warhead bursts at location (ξ, η) . Now define $P_K[(r, \theta)(\xi, \eta)]$ to be the unconditional probability of kill of a target element whose location is given by (r, θ) as follows:

$$P_K[(r, \theta), (\xi, \eta)] = P_{K/T}[(r, \theta)/(\xi, \eta)] f_H(\xi, \eta) \quad (1)$$

Next, define $P_{KT}(\xi, \eta)$ to be the unconditional probability of kill by a single warhead which bursts at location (ξ, η) and is given by:

$$P_{KT}(\xi, \eta) = \int_0^{2\pi} \int_0^R P_{K/T}[(r, \theta)/(\xi, \eta)] f_H(\xi, \eta) r dr d\theta \quad (2)$$

$$P_{KT}(\xi, \eta) = f_H(\xi, \eta) \int_0^{2\pi} \int_0^R P_{K/T}[(r, \theta)/(\xi, \eta)] r dr d\theta \quad (3)$$

Finally, define the Mean Area of Effectiveness (MAE) as:

$$MAE = \int_0^{2\pi} \int_0^R P_{K/T}[(r, \theta)/(\xi, \eta)] r dr d\theta \quad (4)$$

The Mean Area of Effectiveness is commonly used to compare effectiveness of an artillery warhead. Using the MAE, we have:

$$P_{KT}(\xi, \eta) = MAE \cdot f_H(\xi, \eta) \quad (5)$$

b. Cluster Bomblet Warhead—Lethal Area

Consider the special case where the target elements are uniformly distributed in a circle of radius R , and a cluster of m bomblets

(an equivalent area element that is killed by one bomblet). Then P_{KW}^m is the probability that a target element will be killed by at least one bomblet in the warhead and is given by:

$$P_{KW}^m = 1 - \left(1 - \frac{A_L}{\pi R^2}\right)^m \quad (6)$$

c. Evaluation of the Proportion of Target Area That is Destroyed by a Salvo of n Rockets

All the dispersion factors can be divided into two categories:

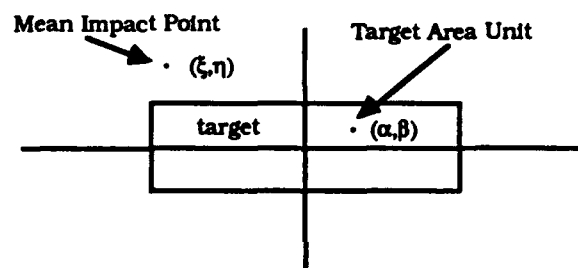
- Precision factors that create a dispersion of the salvo around the Mean Point of Impact (MPI)
- Accuracy factors that create a bias miss distance error of the whole salvo from the target center

The bias and precision factors are independent and randomly distributed according to the following:

Precision: $f_p(X,Y) \sim \text{BIVARIATE NORMAL}(0,0,\sigma_x,\sigma_y)$

Bias: $f_b(\xi,\eta) \sim \text{BIVARIATE NORMAL}(0,0,\sigma_\xi,\sigma_\eta)$

Using the following diagram,



we can define the following probabilities:

P_k^1 = Probability of killing a target area element at (α, β) with one warhead,

$$P_k^1(\alpha, \beta / \xi, \eta) = \frac{MAE}{2\pi\sigma_x\sigma_y} e^{-\frac{1}{2}\left[\left(\frac{\alpha-\xi}{\sigma_x}\right)^2 + \left(\frac{\beta-\eta}{\sigma_y}\right)^2\right]} \quad (7)$$

and

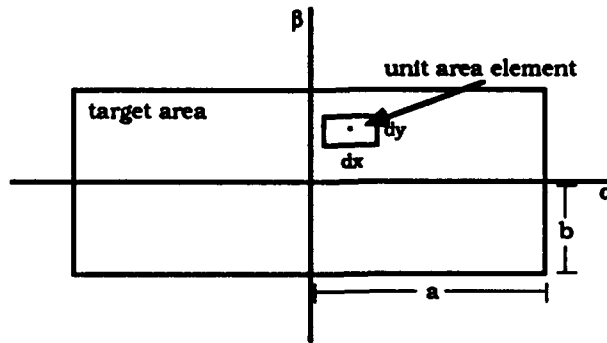
P_k^n = Probability of killing a target area element at (α, β) with a salvo of n warheads.

$$P_k^n(\alpha, \beta / \xi, \eta) = 1 - (1 - P_k^1)^n \quad (8)$$

Recall from equation 6 that P_{kw}^m is the probability that at least one bomblet from a warhead of m bomblets will kill the target. The term P_k^1 in equation 8 will use P_{kw}^m in the Target Damage Assessment Program given in Appendix B. Additionally, we define $G(\xi, \eta)$ as the expected beaten area of the target covered after a whole salvo:

$$E[A_T / \xi, \eta] = G(\xi, \eta) = \int_{-a}^a \int_{-b}^b P_k^n(\alpha, \beta / \xi, \eta) dx dy \quad (9)$$

This is illustrated in the following diagram:



Generalizing, we have:

$$E[A_T] = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{G(\xi, \eta)}{2\pi\sigma_\xi\sigma_\eta} e^{-\frac{1}{2}\left[\left(\frac{\xi-X_0}{\sigma_\xi}\right)^2 + \left(\frac{\eta-Y_0}{\sigma_\eta}\right)^2\right]} d\xi d\eta \quad (10)$$

where:

- $E[A_T]$ The expected kill area from all possible salvos with all possible (ξ, η) .
- X_0, Y_0 The center of all possible salvos that can be taken as the center of the target (approximately, because sometimes a small fixed bias exists).

For a salvo of n rounds, we have:

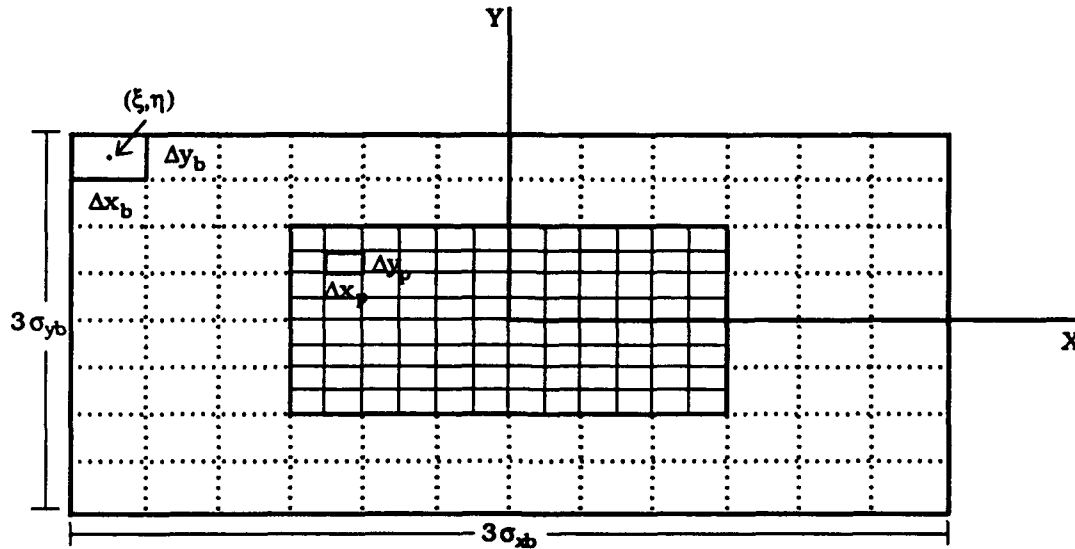
$$P_{SK}^n = \frac{E[A_T]}{4 \cdot a \cdot b} \quad (11)$$

where

- P_{SK}^n The proportion of target that is killed by a salvo of n rounds.

d. Numerical Solution Method

The above relationships can be evaluated in the following manner:



A large space around the target, of size $3\sigma_{xb} \times 3\sigma_{yb}$, is divided into small cells. The center of each cell will be denoted as the

argument (ξ, η) and the corresponding $G(\xi, \eta)$ will be calculated for each cell. Then,

$$E[A_T] = \sum_{i \in X} \sum_{j \in Y} G(\xi, \eta) \cdot f_b(\xi, \eta) \Delta X_b \Delta Y_b \quad (12)$$

where

$$f_b(\xi, \eta) = \frac{1}{2\pi\sigma_x\sigma_y} e^{-\frac{1}{2}\left[\left(\frac{\xi}{\sigma_x}\right)^2 + \left(\frac{\eta}{\sigma_y}\right)^2\right]} \quad (13)$$

and the proportion of the destroyed target or the probability that one element target is destroyed by a salvo of n rounds is:

$$P_K^n = \frac{E[A_T]}{4ab} \quad (14)$$

2. Model Application

A FORTRAN program was written incorporating the above model. The FORTRAN program code is given in Appendix A. The following results are from one set of system data made up for this program.

Results:

DESTRUCTION PROBABILITY = .4036

DESTROYED AREA (SQM) = 2018.

PDF INTEGRAL = .9946

Data:

NO. OF ROUNDS = 10

MEAN AREA OF EFFECTIVENESS (SQM) = 7877.5

TARGET HALF WIDTH (M) = 100.00

TARGET HALF LENGTH (M) = 50.00

PRECISION CROSS-RANGE STANDARD DEVIATION (M) = 100.0

PRECISION RANGE STANDARD DEVIATION (M) = 100.0

BIAS RANGE STANDARD DEVIATION (M) = 100.0

BIAS CROSS RANGE STANDARD DEVIATION (M) = 100.0

NO. OF SEGMENTS ON TARGET 10. X 10.

NO. OF SEGMENTS ON THE OPEN AREA 25.X 25.

The target pattern that is used for this program is a quarter of a rectangle. Since the target is homogeneous, the killing probability of each area element in one quarter is identical to a corresponding element in the other three. Therefore, it is sufficient to integrate over one-quarter of a target rather than the entire rectangle.

3. Program Execution Analysis

1. The number of segments in the open area (last line) were found to be insensitive—any values greater than 10 gave very similar results.
2. PDF integral (line 3) is an integration of equation 13 over the whole space. It is given as an indication of the accuracy of this numerical integration. The value accepted is sufficiently close to 1.
3. The above results will be used in comparison with the Monte Carlo simulation that will be described later.

B. SIMULATIONS OF TARGET DAMAGE ASSESSMENT FROM CLUSTER BOMBLET WARHEADS

1. Simulation Program of Small Targets When Firing Unit Size is Not Considered

The program reads system and target data. It calls for the *Salvo-round* subroutine to simulate the damage level caused by firing variable rounds in a salvo.

While receiving each one of the salvo results, the program calls for the *Statistics* subroutine that calculates averages, standard deviations, and confidence intervals consecutively.

The program stops when the confidence interval for 95 percent confidence level is reduced to predetermined fixed values ("resolution"). Simulation of five target types that are deployed on the same area can be handled simultaneously.

Typically, any combination of five target types can be chosen from the following: tank, APC, artillery gun, soft vehicle, standing troops, prone troops, and troops in excavations.

a. Subroutine Salvoround

The subroutine accepts the target elements linked by a linked list matrix, generates bias error, generates precision error, searches for target elements inside the pattern ellipse— if found, they are eliminated from the list— and counts the number of eliminations. When the number of predetermined rounds in the salvo are completed, the subroutine returns the number of destroyed target elements to the main program.

The program uses subroutine *Rannum*, which is a random number generator. (Professor M. Bailey of the Naval Postgraduate School distributed this program to students of his Simulation class; the FORTRAN code list is given in Appendix B.)

b. Assumptions

1. The bomblet pattern on the ground is an ellipse in which the bomb-lets are dispersed evenly.
2. Bias distribution and precision distribution are both independent bivariate normal with all means equal to 0.

c. Testing the Program

Running the program using the made-up data shown in subsection A.2 of this chapter with the same target yielded the following result: "damage level" (called "destruction probability" or "destroyed area proportion") = 0.397. Comparing it to 0.4036, which is obtained by the integration program, there is a difference of 1.6 percent. That difference can be explained by the termination of the simulation program when the half 95 percent confidence interval reaches a predetermined value, which had been previously fixed at 1.6 percent. Therefore, the results of the two programs agree (with a 95 percent confidence level).

Figures 1 through 3 describe the procedure.

The FORTRAN program code is given in Appendix B.

2. Simulation Program for Small Targets When Firing Unit Size and Rate of Firing Are Considered

This program is similar to the previous one. The difference is that the bomblet lethal area, when firing on troop target elements, is decreased during the elapsed salvo time.

It is conceivable that standing troops, while exposed to fire, will try to find shelter. At first, they go to a prone position, and then they crawl to a shelter, which is assumed to be an excavation. For the purpose of the simulation, it is assumed that all troops are standing at time zero (i.e., the lethal area values are those of standing troops) and the lethal area is decreased exponentially with elapsed salvo time.

The lethal area at time t is given by:

$$ALT = ALX + (ALST - ALX) \cdot \text{EXP} (- \text{GAMMA} \cdot \text{TIME})$$

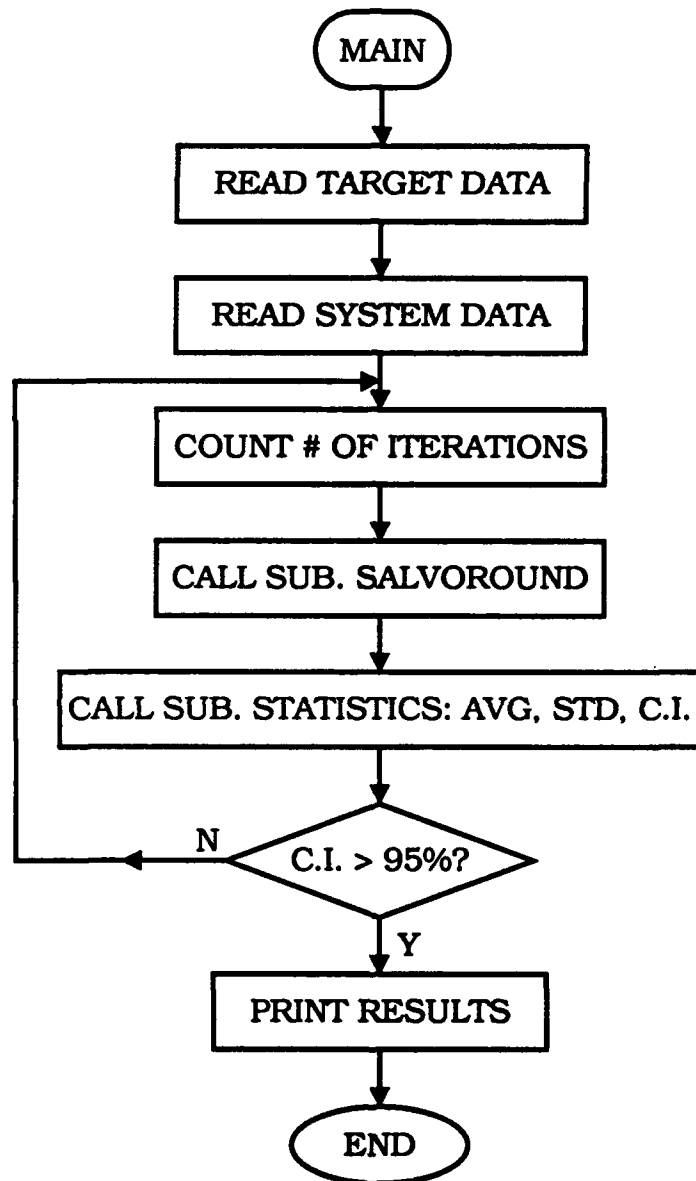


Figure 1. **Simulation Main Program Flow Chart**

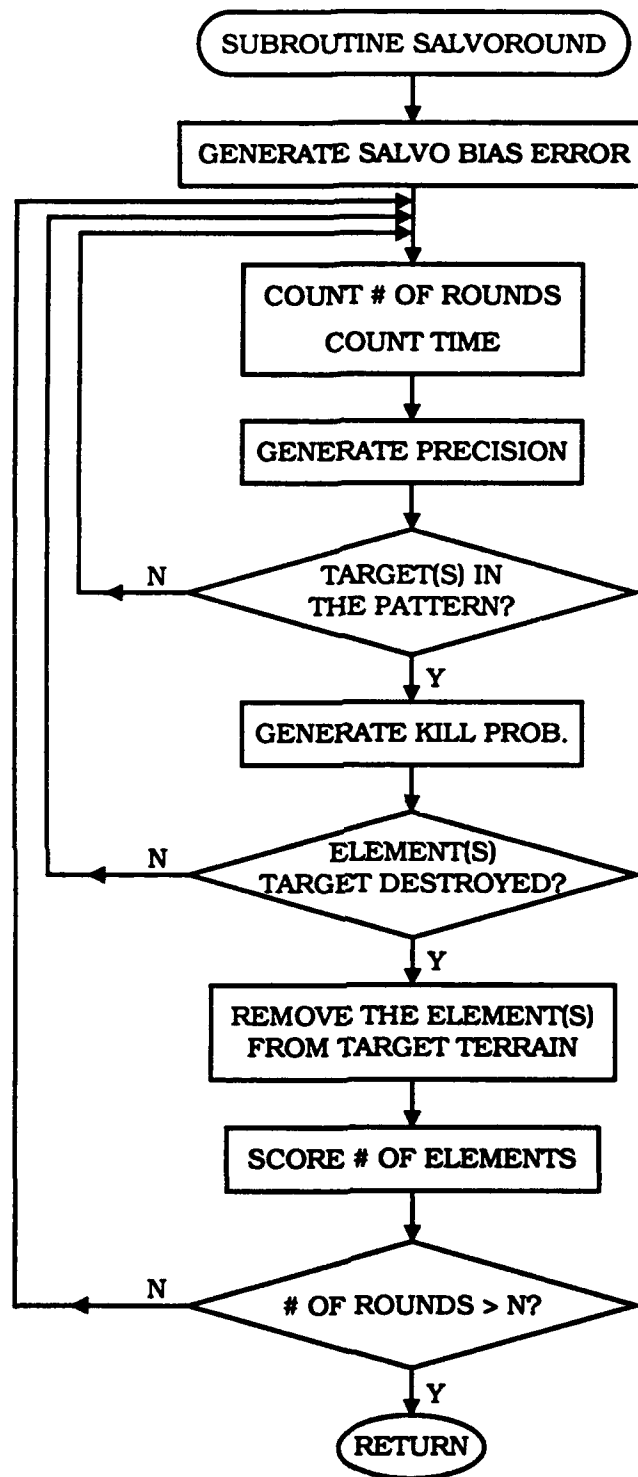


Figure 2. Subroutine Salvoround Flow Chart

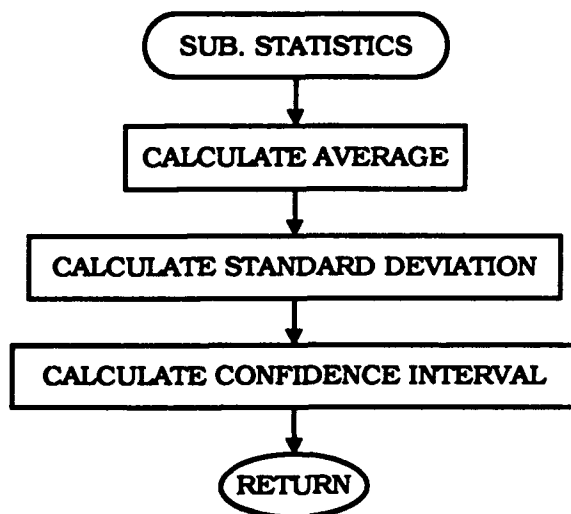


Figure 3. Subroutine Statistics Flow Chart

where GAMMA is the individual-finding-shelter rate and ALST and ALX are lethal areas of troops when standing and when in excavations, respectively.

C. SIMULATION OF TARGET DAMAGE ASSESSMENT FROM SMART SUBMUNITION WARHEADS

This simulation assessed damage to targets consisting of hard elements (armor vehicles, tanks) when hit by Sensor Fuzed Munitions (SFM).

The main program is similar to the main program for cluster munitions (B1); it calls for subroutine *Smartsalvo*. This subroutine accepts the target elements (listed in x , y location arrays), generates a bias error, generates precision error, generates submunition dispersion, and then searches for target elements inside the submunition searching circle. If targets are found, they are recorded in a stack for detected elements. Among the potentially detected targets, one killed target per one

submunition is chosen, in order of the farthest from the searching center first. Finally, the subroutine counts the number of killed targets. When the predetermined number of salvo rounds is completed, the subroutine returns the number of destroyed units to the main program. A flow chart of the subroutine is given in Figure 4.

The following two additional computations are required:

1. **Function PH1:**

This function determines the hit probability, given the existence of a target inside the submunition searching circle.

2. **Function PK1:**

This function determines the kill probability, given the existence of a target inside the submunition searching circle.

The FORTRAN program codes are listed in Appendix B.

D. OTHER PROGRAMS

1. **Dealing With Large Targets**

When the target is large, it is necessary to shift the aiming point in order to cover the entire target area.

The multi-aiming point procedure is essential, particularly with a more accurate weapon. A more accurate weapon hits the target at the center and the margins remain uncovered. If the weapon ballistic dispersion is high, this procedure is less important because the dispersion creates target coverage.

Functions Splitx and Splity deviate the aiming point for large targets from the center to the outer portions of the target. These functions evenly allocate the salvo rounds among the subtargets. Residuals are directed to central portions.

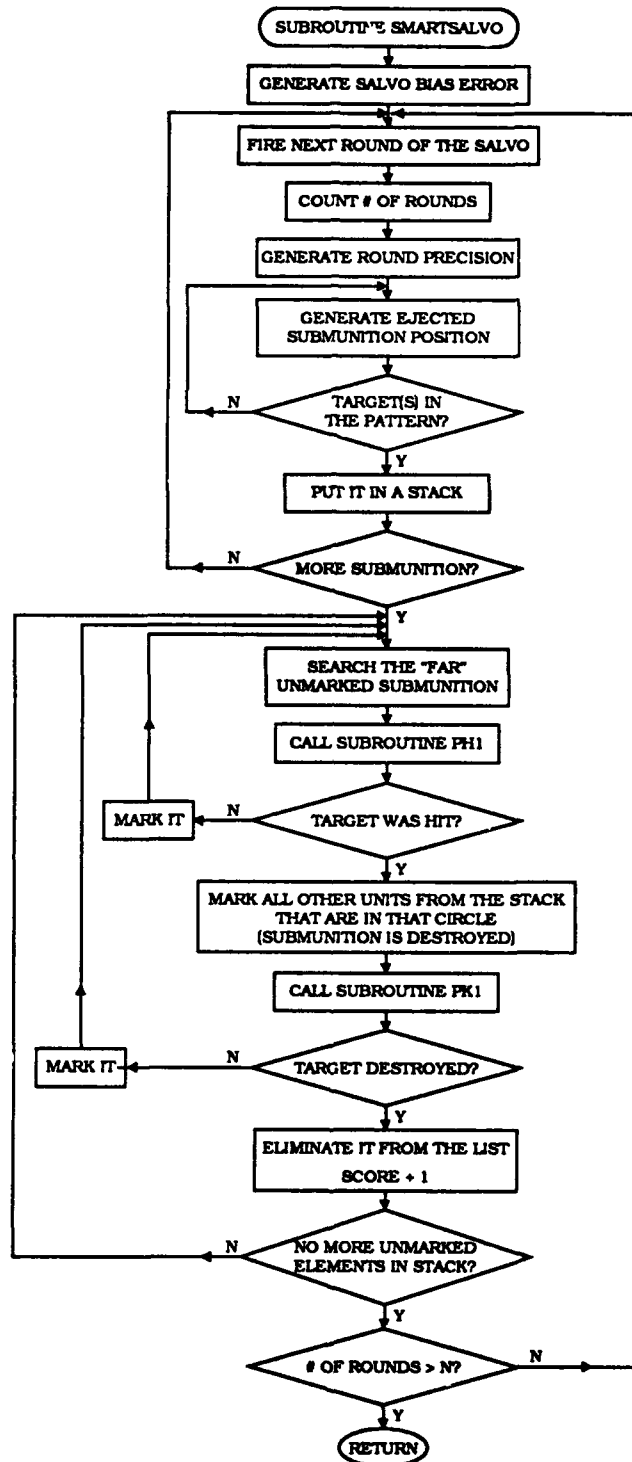


Figure 4. Subroutine Smartsalvo Flow Chart

FORTTRAN function codes are listed in Appendix B.

2. Consecutive Statistical Calculations

The following function and subroutines were also used:

- **Subroutine Statistics** calculates the average of a current incremented sample and calls for subroutine Stdev to calculate the standard deviations.
- **Subroutine Stdev** calculates the standard deviations.
- **Function Confint** calculates the confidence intervals.
- **Subroutine Rannum**: A random number generator that provides all basic distributed random numbers.

FORTTRAN codes are listed in Appendix B.

E. RUNNING THE PROGRAM

1. Systems Data

a. Range

The analysis was done with a range of 27 km, which was chosen in order to include the 155 mm extended-range howitzer gun projectile (whose maximum range is 27 km) in the comparison analysis. Despite the general opinion of "experts" that modern guns can reach ranges longer than 27 km, the author's opinion is that this range is the practical limit of standard artillery. Tube artillery will remain at this range because any optional extension of range will be accompanied by degradation of accuracy as well as rate of fire. Hence, free-flight artillery rocket systems will do the job more effectively.

The maximum range of the MARS is 33 km. The range could actually be longer, but it was limited to 33 km due to the high dispersion of the rockets.

The TCAR range is 45 km. The range can be extended by using larger caliber rockets. The accuracy of the TCAR is not dependent on the range.

The main reasons this thesis used a 27 km range are: (1) this range is common to the above three systems; (2) by convention, 27 km is regarded as the typical artillery range for analysis purposes; and (3) the range is coincident with the limit of battlefield real-time intelligence (that limit may be extended in the near future, when the use of drones (RPVs) will be more extensive).

The following data are related to the 27 km range.

b. Accuracy

Bias (sometimes called "ballistic") distribution (i.e., shift of the whole salvo from the center of target) and precision distribution (i.e., dispersion of the salvo around the center of impact) are bivariate normal with means 0 and standard deviations σ_{BX} , σ_{BY} for bias and σ_{PX} , σ_{PY} for precision.

The standard deviations were calculated while taking into account all dispersion factors. The ballistic behavior of a free-flight object (a projectile as well as a rocket) creates independently distributed bias and precision deflections in the X and Y directions. These are shown in Table 1.

The analysis was done by running the simulation program for cluster warheads on the targets to be described.

TABLE 1
DISPERSION STANDARD DEVIATIONS

System/Dispers.	σ_{PX} m	σ_{PY} m	σ_{BX} m	σ_{BY} m
G155	170	36	108	34
MARS	214	187	127	107
TCAR	60	60	5	5

The target location errors are assumed to have a bivariate normal distribution with mean 0 and standard deviations σ_x and σ_y , chosen to be: 0, 25, 50 and 100 m. The Target Location Error (TLE) was pooled with the bias deviation as follows:

$$\sigma_{BXTOT} = \sqrt{\sigma_{BX}^2 + \sigma_{TLEX}^2}; \sigma_{BYTOT} = \sqrt{\sigma_{BY}^2 + \sigma_{TLEY}^2}$$

Note: The variances involved are from independent random variables.

c. Rate of Fire

- One gun—G155 can fire at the rate of three rounds per minute. Maximum rate of a battery of six— 18 rounds per minute.
- MARS—one target is engaged by no more then one launcher at a time, with rate of 36 rounds per minute.
- TCAR— 36 rockets are available on a launcher, but the ground control system is capable of controlling 20 rockets in flight simultaneously (no matter from where they were fired). Since the flight trajectory time is approximately one minute, the rate of fire is 20 rounds per minute.

d. Marginal Price

Cost analysis comparisons of target damage levels between the three systems were carried out. This was done by taking into consideration the marginal cost—the cost of the rounds that were allocated to

the particular target (because they directly cause the damage to the target).

Another aspect of this topic is that the costs of Self-Propelled Guns (SPGs) and Multiple-Rocket Launchers (MRLs) are almost the same. Ground support equipment and logistics are also identical.

The exact costs of all system parts were not available. In addition, costs of weapon systems are subject to changes according to various contract factors. Therefore, reasonable costs were estimated based on the author's experience. Table 2 shows cost estimates for one round of each system.

TABLE 2
ROUND COSTS IN DOLLARS

System/Cost	Cluster Bomblet Wh.	SFM Wh.*
G155	\$2,000	\$37,000
MARS	\$7,000	\$112,000
TCAR	\$11,000	\$116,000

*It is assumed that SFM target production cost is \$35,000 and the canisters that contain it cost the same as the bomblets in the cluster version.

e. Cluster Warhead Data

The three systems with cluster warheads accommodated with CL2130 at/am bomblets are IMI Ltd. products. The bomblet is equipped with a time-operated self-destruction mechanism that eliminates the problem of duds.

Diameter: 42 mm

Length: 55 mm

Weight: 300 grams

Maximum hard steel penetration depth: 110 mm

Remark: This bomblet is not the M42-M77 commonly used by the US and NATO.

TABLE 3
SYSTEMS CLUSTER WARHEAD DATA

System	Diameter (mm)	# of Bomblets	Radius of Pattern (m)
G155	155	49	75
MARS	160	104	100
TCAR	160	104	100

Bomblet lethal area:

Standing troops: 197 sqm

Prone troops: 83 sqm

Troops in an open excavation: 1 sqm

(It is assumed that only a direct hit into the excavation is effective.)

Tank (T62): 3.5 sqm

APC (BTR50): 5.0 sqm

SPG: 7.0 sqm (in this case, neutralization is considered rather than destruction)

Trucks: 20 sqm

f. SFM Submunition Warhead

Warheads are accommodated with 155 mm SFM, and each is carried inside a canister. Data for SFM submunitions are classified, so this thesis will not specifically identify the submunitions. Performances that are listed are the best guess of the author.

TABLE 4
SYSTEMS SFM WARHEAD DATA

System	Diameter (mm)	# of Canisters	Ejection Distance (m)		
G155	155	1	mean	0	sd. 5
MARS	160	3	mean	40	sd. 10
TCAR	160	3	mean	40	sd. 10

There are three stages to the operation, with three different probabilities. Given a target inside the searching circle:

- **Detection probability** is expected to be high, therefore considered to be 1.
- **Hit probability (PH)**— Given the target is detected, the probability that the forged accelerated penetrator hits the target in a vulnerable location.
- **Kill probability (PK)**— Given a target is hit, the probability of penetration and destruction.

PH and PK are functions of the distance of the target from the center of the searching circle (see Table 5):

TABLE 5
SFM SUBMUNITION DATA

Section	Radius (m)	PH	PK-TANK	PH-APC
Inner Circle	25	0.9	0.3	0.6
Intermediate Circle	45	0.65	0.25	0.50
Max. Search Circle	75	0.50	0.2	0.40

False targets were not taken into account because information about that phenomenon was not available.

2. Simulation Output

The programs were run on the mainframe computer (IBM 3033), controlled by exec programs. The number of rounds in the salvo were incremented after each simulation inside the main program, going from minimal to maximal relevant salvo size. The output file is a matrix in which the first row contains the salvo size and the other rows contain the simulation results. The results were analyzed by a GRAFSTAT software package and are presented in the next chapter.

III. TARGET DAMAGE ASSESSMENT

A. TARGET DESCRIPTIONS AND RESULTS

The tools that were developed in the last chapter were implemented to assess damage to some typical targets.

1. Target Number 1: Uniform And Homogeneous Density—Troops

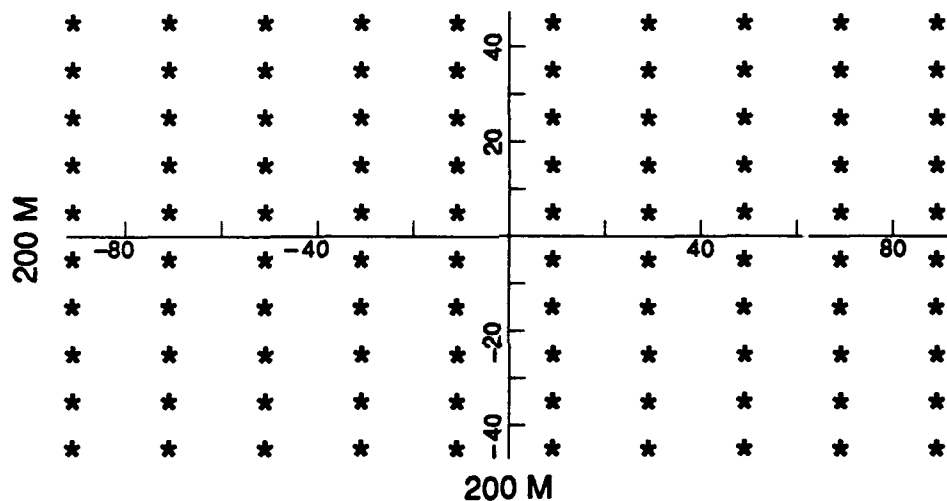


Figure 5. Target No.1

a. Description:

Object: Personnel
Number of units: 100
Target area size (m): 200(width)x200(depth)
Positions:
1.1 Standing
1.2 Prone

- 1.3 Position change during salvo: Initially troops are standing; then all are prone or entering into top open shelters. "Prone function" is an exponentially decaying function (rate = 60 seconds).

Target location error (one standard deviation):

Intelligence quality:

Good:	25 (m)
Regular:	50 (m)
Fair:	100 (m)

Ammunition type: Cluster bomblet warhead (or projectile)

b. Results of 1.1 and 1.2

The simulation results for target number 1 standing troops and marginal costs are shown in Figures 6 and 7, with TLE = 0, 25, 50, 100. The simulation results for target number 1 prone troops and marginal cost are shown in Figures 8 and 9, with TLE = 0, 25, 50, 100.

The following results can be observed from the figures:

1. The more accurate the weapon, the more sensitive it is to TLE.
2. When high target damage is required, sensitivity to TLE increases.
3. Tube artillery is usually less expensive, but the rate of kill is extremely low (divide the number of rounds by the rate of fire— three rounds per minute). In practice, more than one gun should fire at the same target.
4. MARS tends to be relatively more effective when the TLE is large (more than 100 m). However, when the TLE is higher than 100, all results are poor.
5. TCAR is much superior to the other two systems, having a high rate of kill and a capability of achieving a high damage level, but with a slightly higher cost than the G155.

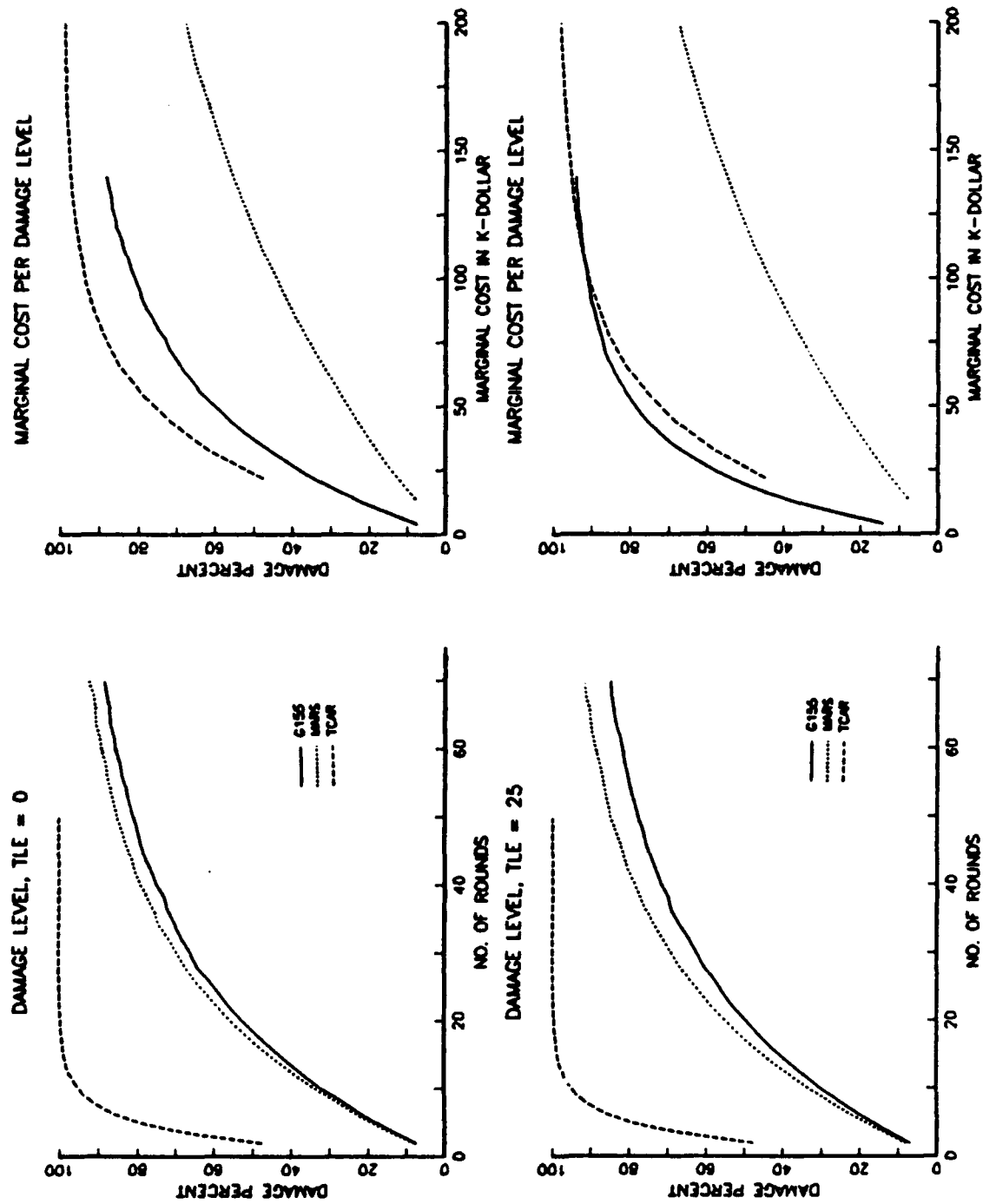


Figure 6. Target No. 1. Standing Troops

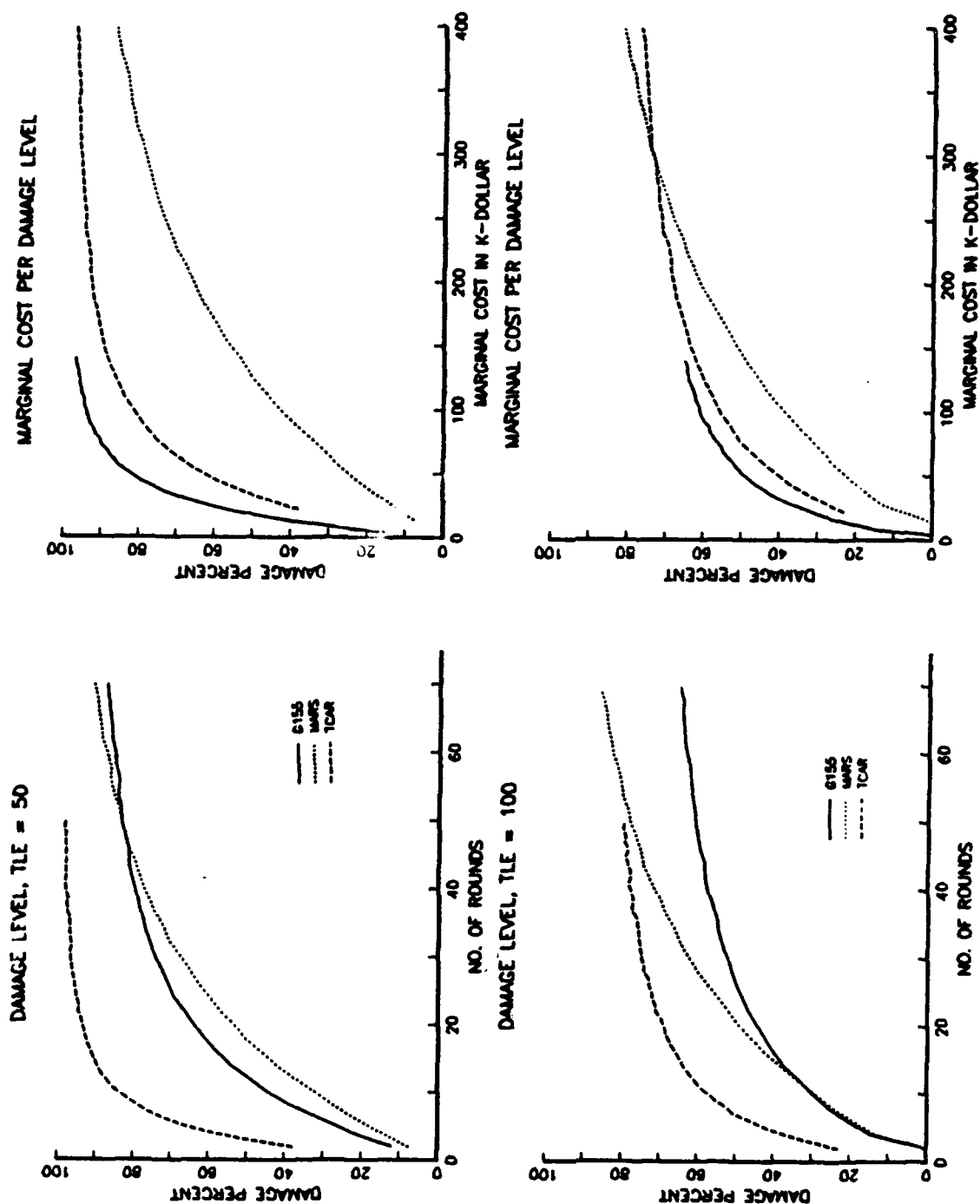


Figure 7. Target No. 1, Standing Troops

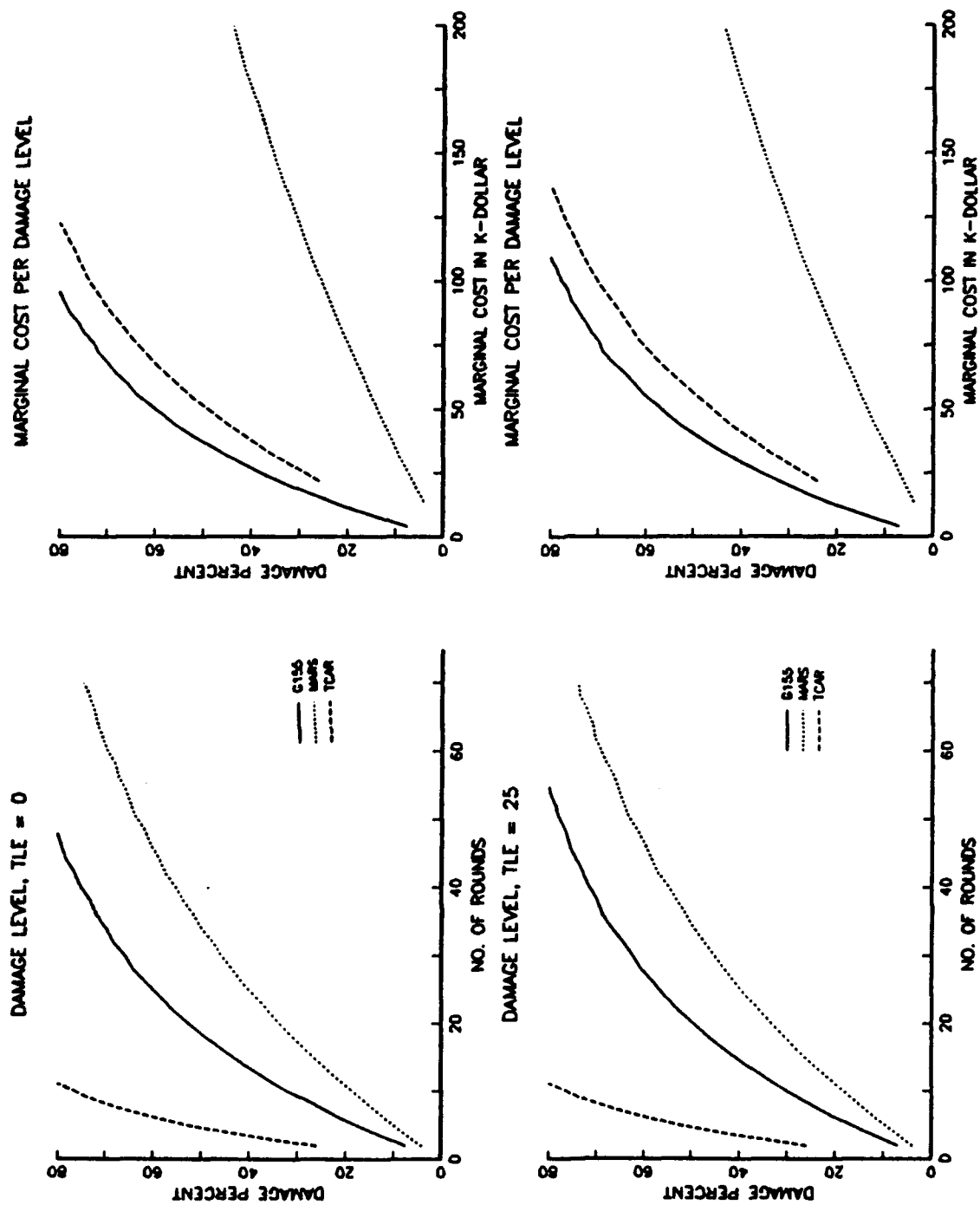


Figure 8. Target No. 1, Prone Troops

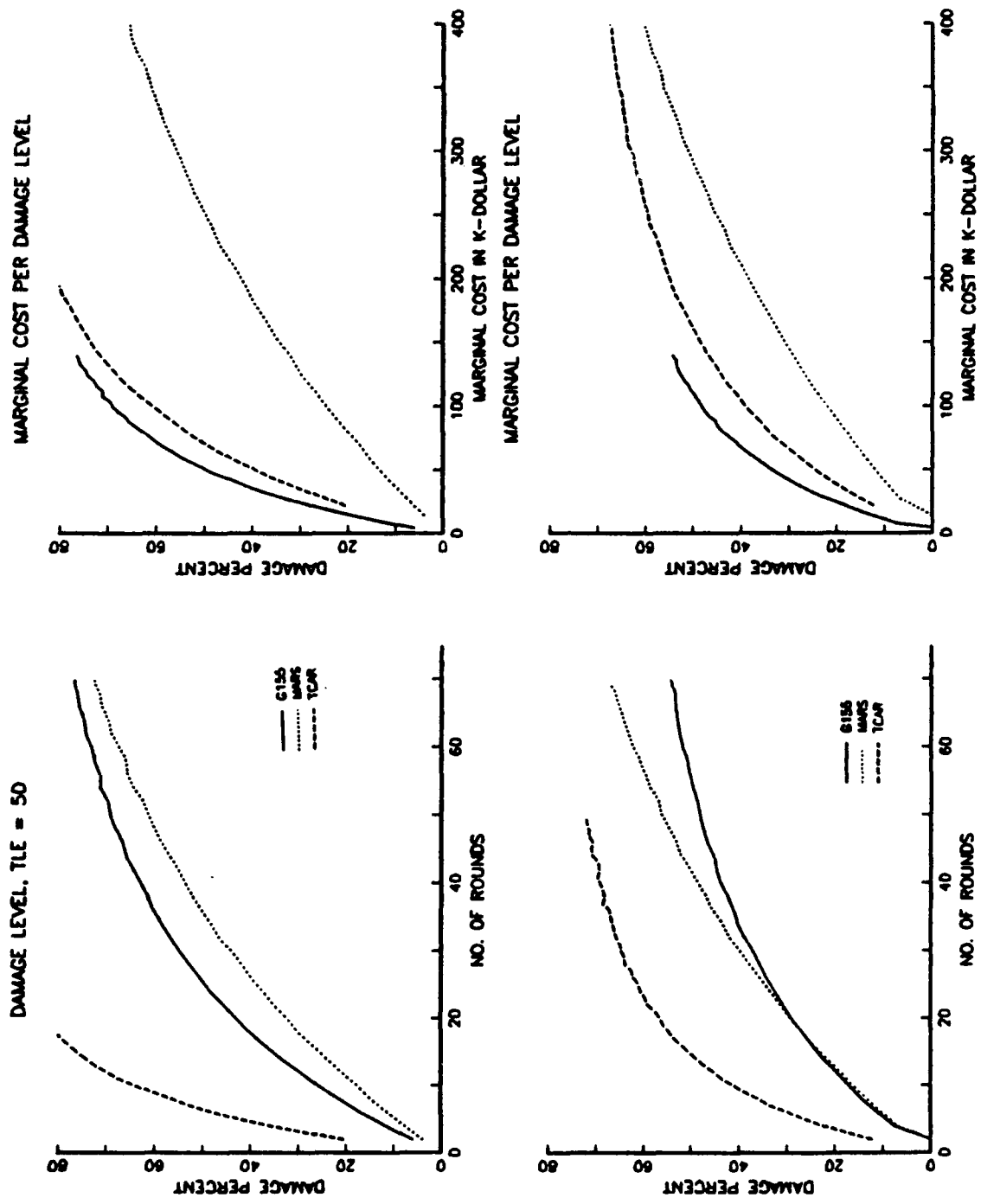


Figure 9. Target No. 1, Prone Troops

c. *Simulation of a Troop Target That Changes Position During Salvo*

Troops find shelter in trenches during a salvo (the rate of finding shelters is 60 seconds). The lethal area of one bomblet when troops are in shelters is one square meter. Figure 10 shows the simulation results.

This case illustrates the degradation of the effectiveness of tube artillery when it is necessary to produce massive fire power on a target. The massive fire power is essential because the objects will probably not stay in place.

These results show that one rocket launcher is capable of producing the same amount of target damage as six guns (maximum 49 percent damage). When firing units on the battlefield are scarce, artillery rocket systems are advantageous, but the cost is high.

Again, the TCAR is far superior to the other systems (maximum 74 percent after 10 rounds).

DAMAGE LEVEL, TLE = 50

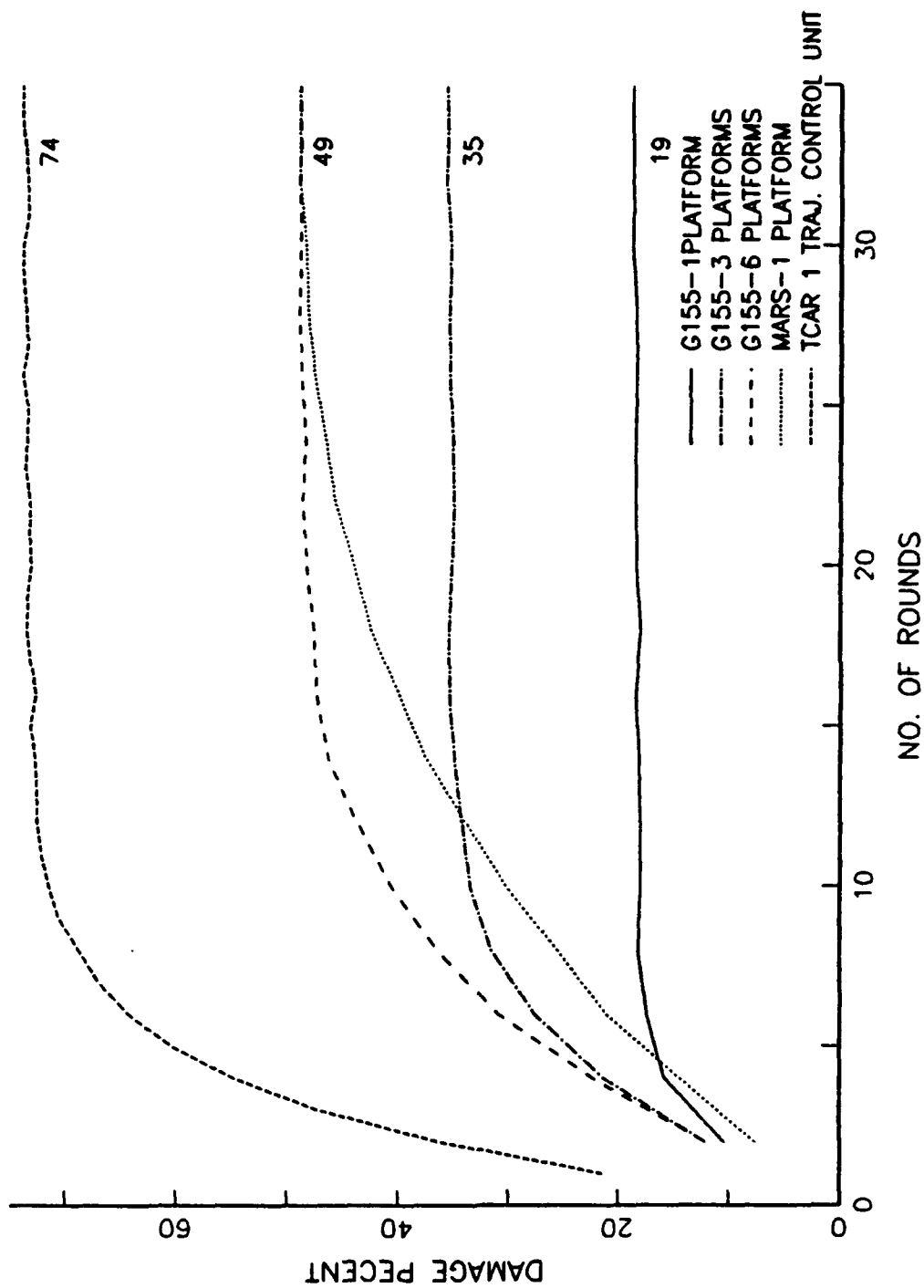


Figure 10. Target No. 1, Standing Troops Finding Shelters

2. Target Number 2: Troops in an Open Area, Nonsymmetrical Homogeneous Target

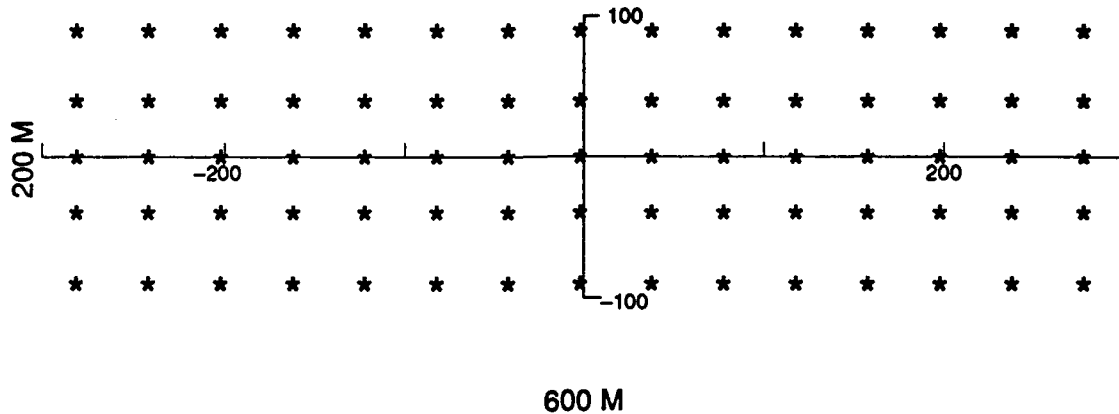


Figure 11. Target No. 2

a. Description:

Object: Personnel

Number of units: 75

Target area size (m): 600 (width) x 200 (depth)

Position: Standing, prone

Target location error (one standard deviation):

Intelligence quality:

Regular: 50 (m)

Ammunition type: Cluster bomblet warhead (or projectile)

b. Results

Target number 2 is a "wide" area target, so the target was divided into sections and the aiming point for each was determined. This split in aiming was done by the function SPLIT, which allocates a number of rounds to each section proportionally. The figures were rounded to

integers by putting a "floor" on the outer sections and a "ceiling" on the inner sections.

The simulation results of target number 2 for standing troops and marginal costs are shown in Figure 12, with TLE = 0, 50. Figure 13 shows the results for prone troops.

Aiming points deviations in x direction are:

155 How. gun (m): 75, -75, 225, -225

LAR160 and TCAR (m): 0, 200, -200

The following results can be observed from the figures:

1. Tube artillery is the most cost-effective, but rate of kill is poor.
2. The artillery rocket is the least cost-effective, but the rate of kill is high—it needed the same number of rounds as the gun, but the rate of fire is 12 times faster.
3. TCAR has a much higher rate of kill. It is less cost-effective than guns, but a much higher damage level can be achieved.
4. Results are less sensitive to TLE (intuitively it is explained by the width of the target).

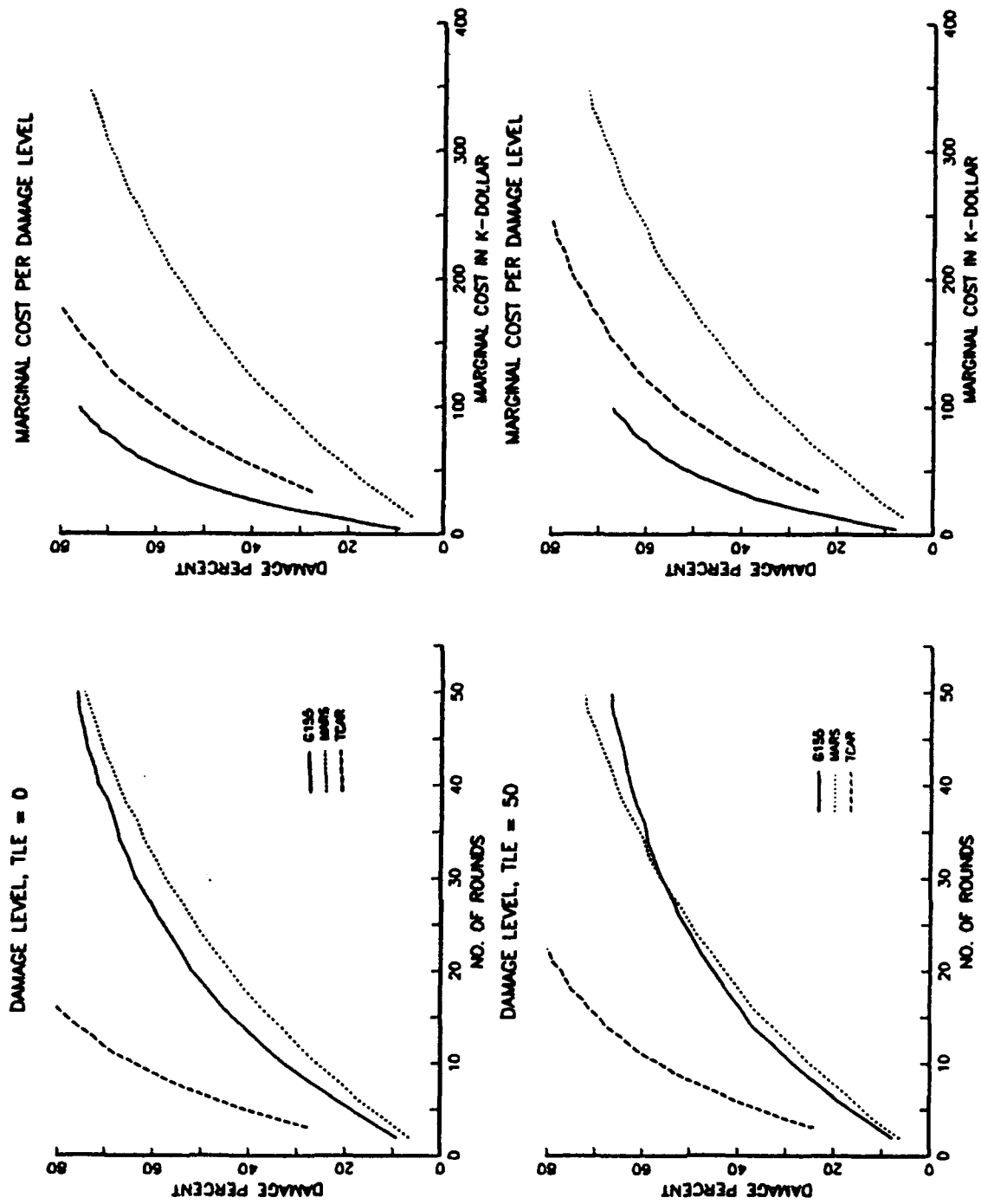


Figure 12. Target No. 2, Standing Troops

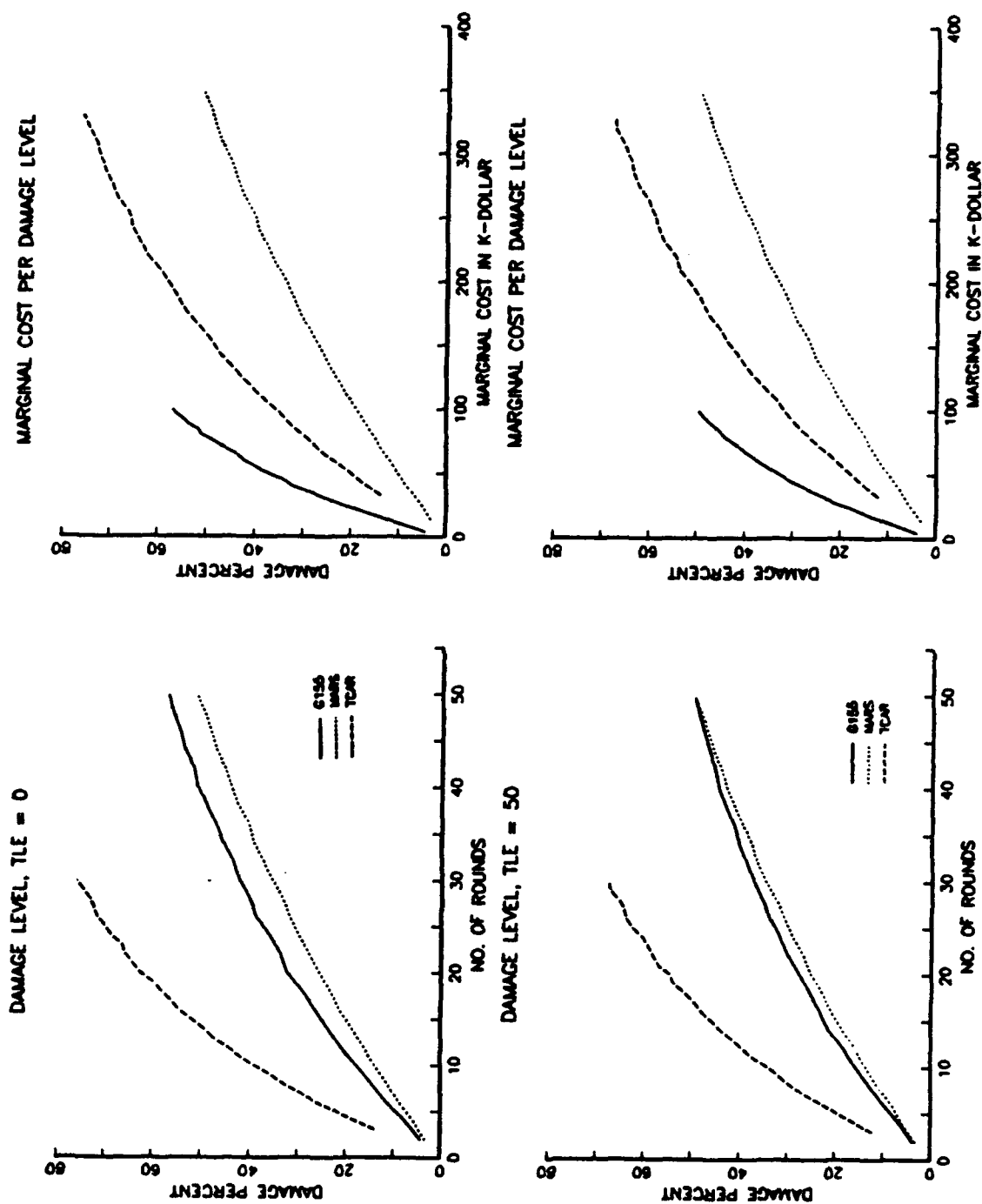


Figure 13. Target No. 2, Prone Troops

3. Target Number 3: Troops in a Company at a Defense Site

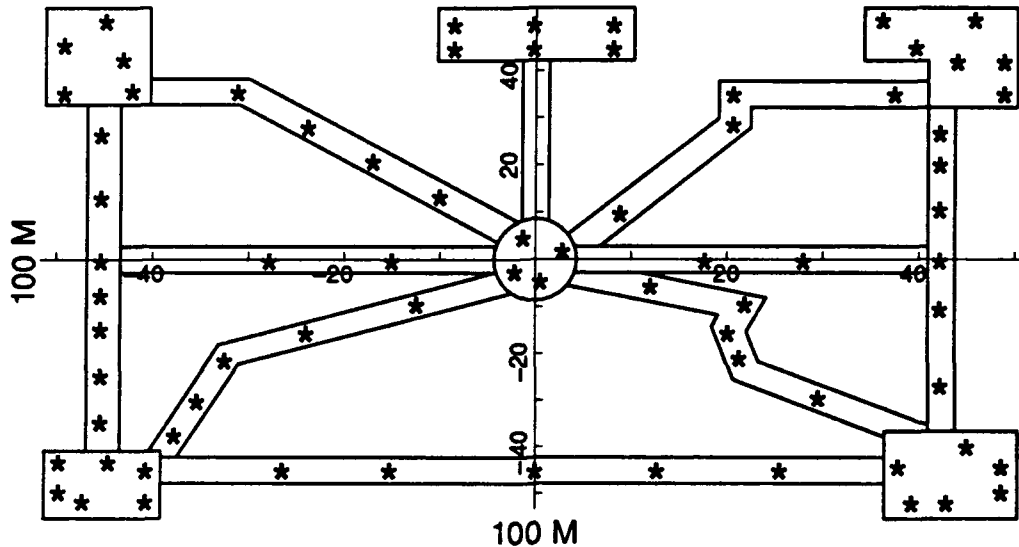


Figure 14. Target No. 3

a. Description

Object: Personnel
Number of units: 76
Target area size (m): 100 (width) x 100 (depth)
Position: Troops in open excavations
Target location error (one standard deviation):
Intelligence quality:
Regular: 50 (m)
Ammunition type: Cluster bomblet warhead (or projectile)

Figure 15 shows the results.

b. Results

The following results can be observed from the figures:

1. The relations between system performances are the same as before.

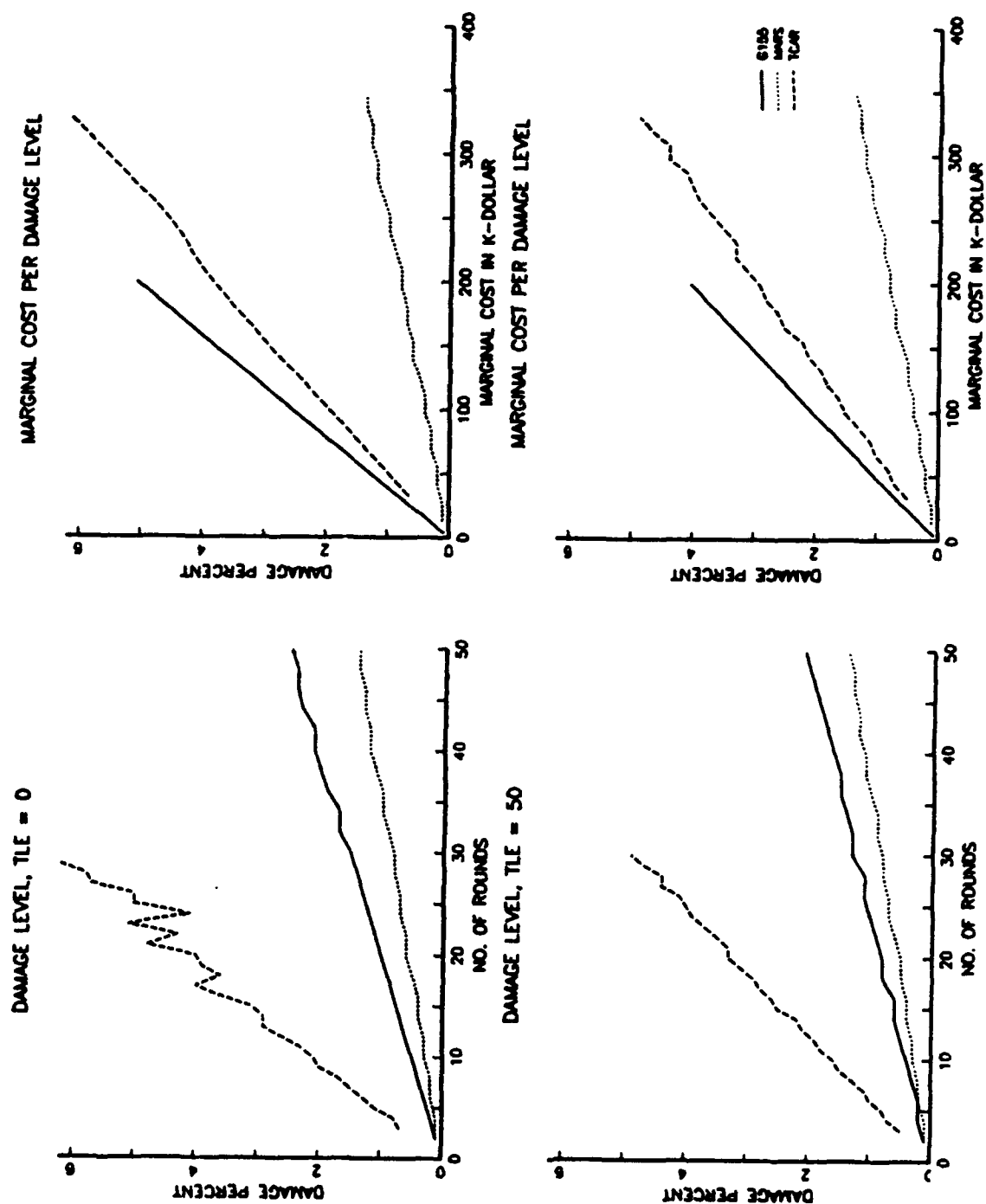


Figure 15. Target No. 3, Troops in Open Shelters

2. All results are very poor—at most six percent damage. Consequently, the cluster bomblet as a submunition is not effective against fortified targets.

We might get better results if we used a greater number of smaller bomblets (M77) in the warheads.

4. Target Number 4: Self-Propelled Armored Howitzer Gun Battery in Firing Deployment

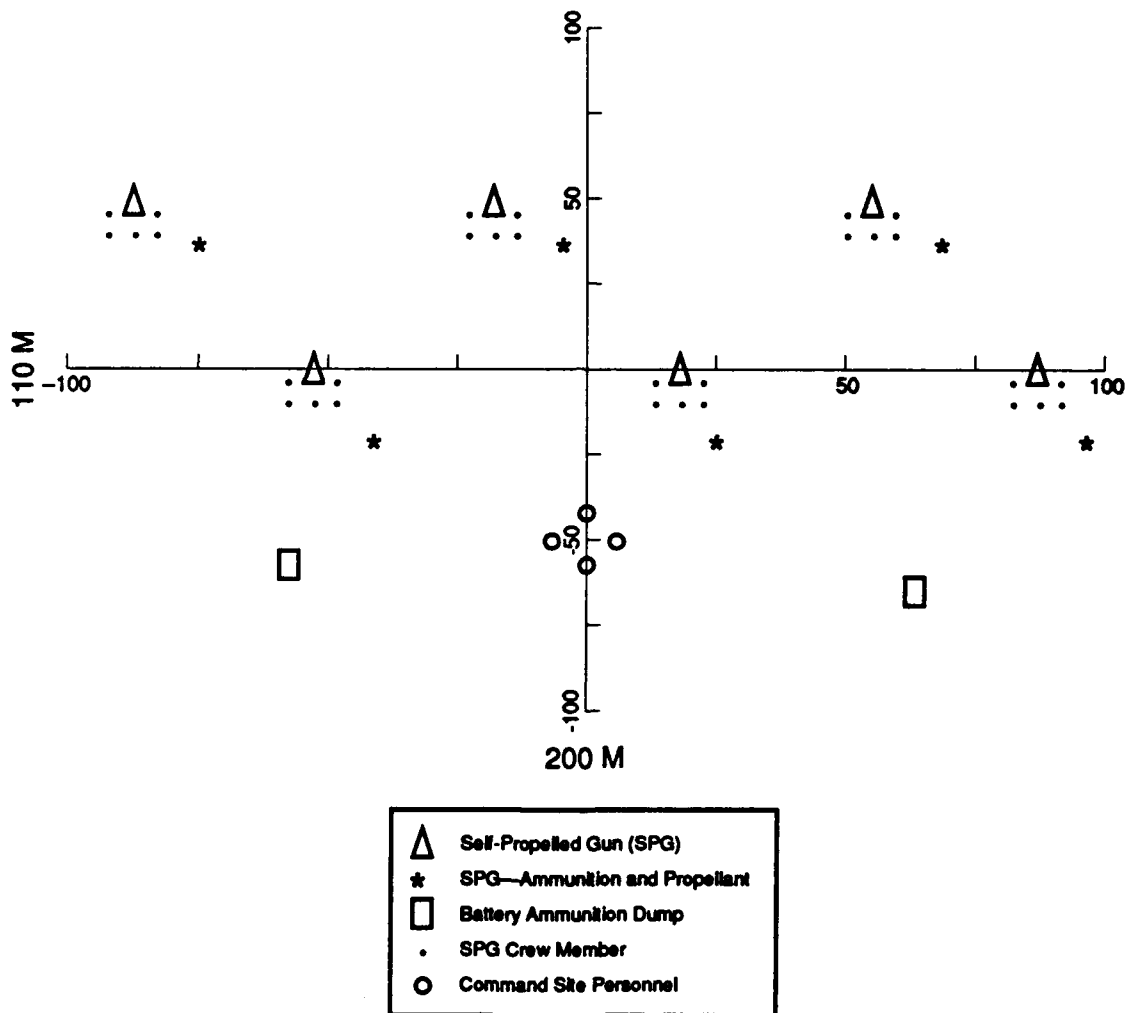


Figure 16. Target No. 4

a. Description

Objects:	Number of Units:
1.1 Armored self-propelled guns	6
1.2 Guns ammunition and propellant piles	6
1.3 Crew members (standing around the gun)	5 x 6
1.4 Battery command site (crouching personnel)	4
1.5 Battery ammunition dump in cases	2

Target area size (m): 200 (width) x 100 (depth)

SPG: "W"-shaped deployment with command post at the center

Ammunition: Beside each SPG, two battery dumps

Target location error (one standard deviation):

Intelligence quality:

Regular 50 (m)

Ammunition type: Cluster bomblet warhead (or projectile)

The following assumptions are made:

1. Only a direct bomblet hit on ammunition or propellant, in cases or in the open, causes detonation. Therefore, the vulnerable area of the ammunition dumps is taken as their base area.
For gun ammunition and propellant piles— 16 sqm.
For battery ammunition dump in cases— 36 sqm.
2. The lethal area of SPG when hit by a bomblet is low. However, it is more practical to use the neutralization area instead. It is sufficient to break down one subsystem inside the SPG in order to stop it from functioning. This area was taken as 10 sqm.
3. A crew is considered to be standing troops. Command site personnel are considered to be crouching troops and the lethal area is assumed to be 100 sqm.

b. Results

Simulation results on gun crew members and command site are shown in Figure 17. Results for the SPGs, gun ammunition, and propellant piles and battery ammunition dump are shown in Figure 18. Marginal costs for the last three are given in Figure 19.

The target is "wide", so two aiming points were chosen:

Deviations in X direction are: +50 m, -50 m

The following results can be observed from the figures:

1. Results for the crews of SPG and command sites show similar behaviors as before. It is important to note that only a few TCAR rounds are needed to destroy the command post crew, resulting in neutralization of the whole battery.
2. TCAR is superior to the other two systems, with a very high killing rate (see Figure 18, all three objects).
3. Guns are the most cost-effective, but they achieve only a limited destruction probability due to their low rate of fire.
4. The probability of detonating ammunition is significant. Such an event causes fatal results and significantly damages guns and crews. Therefore, it is apparent that a cluster weapon is effective as a counterfire weapon. If delivered by TCAR, it is extremely effective.

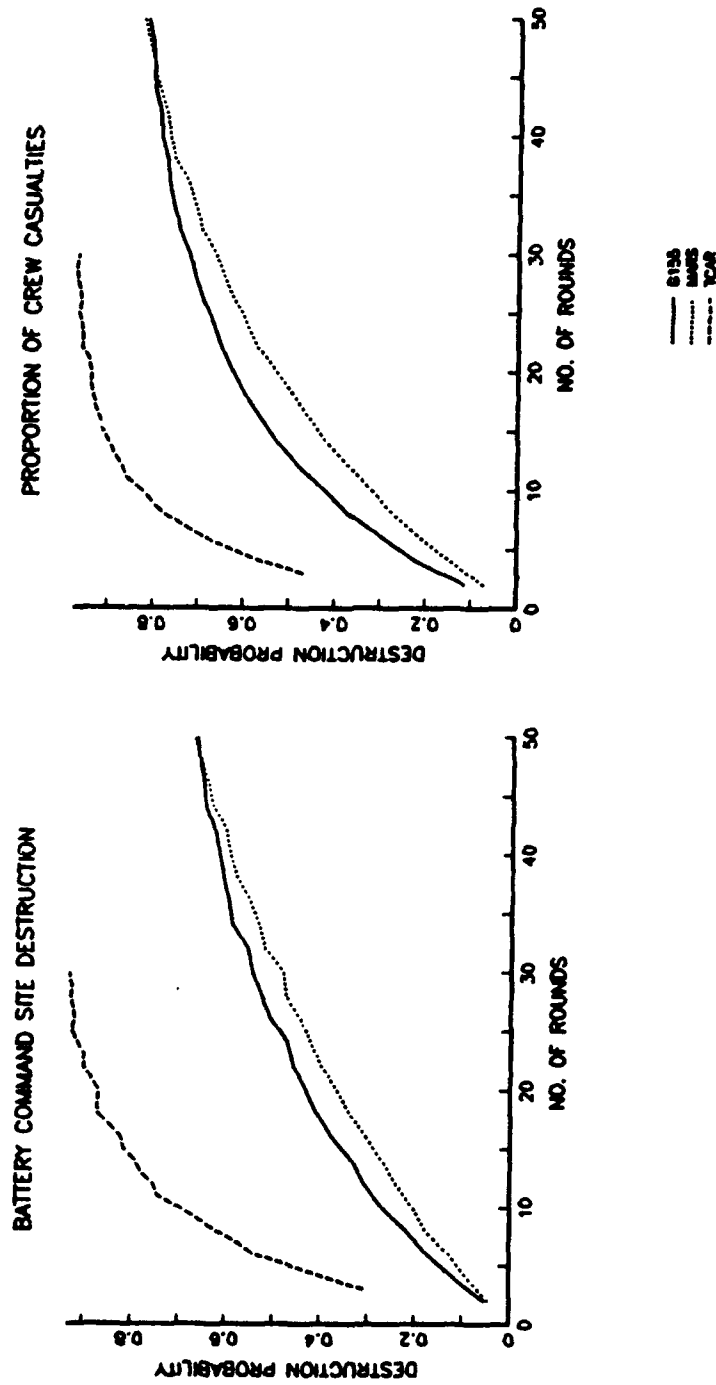


Figure 17. Target No. 4, Artillery Gun Battery, TLE = 50

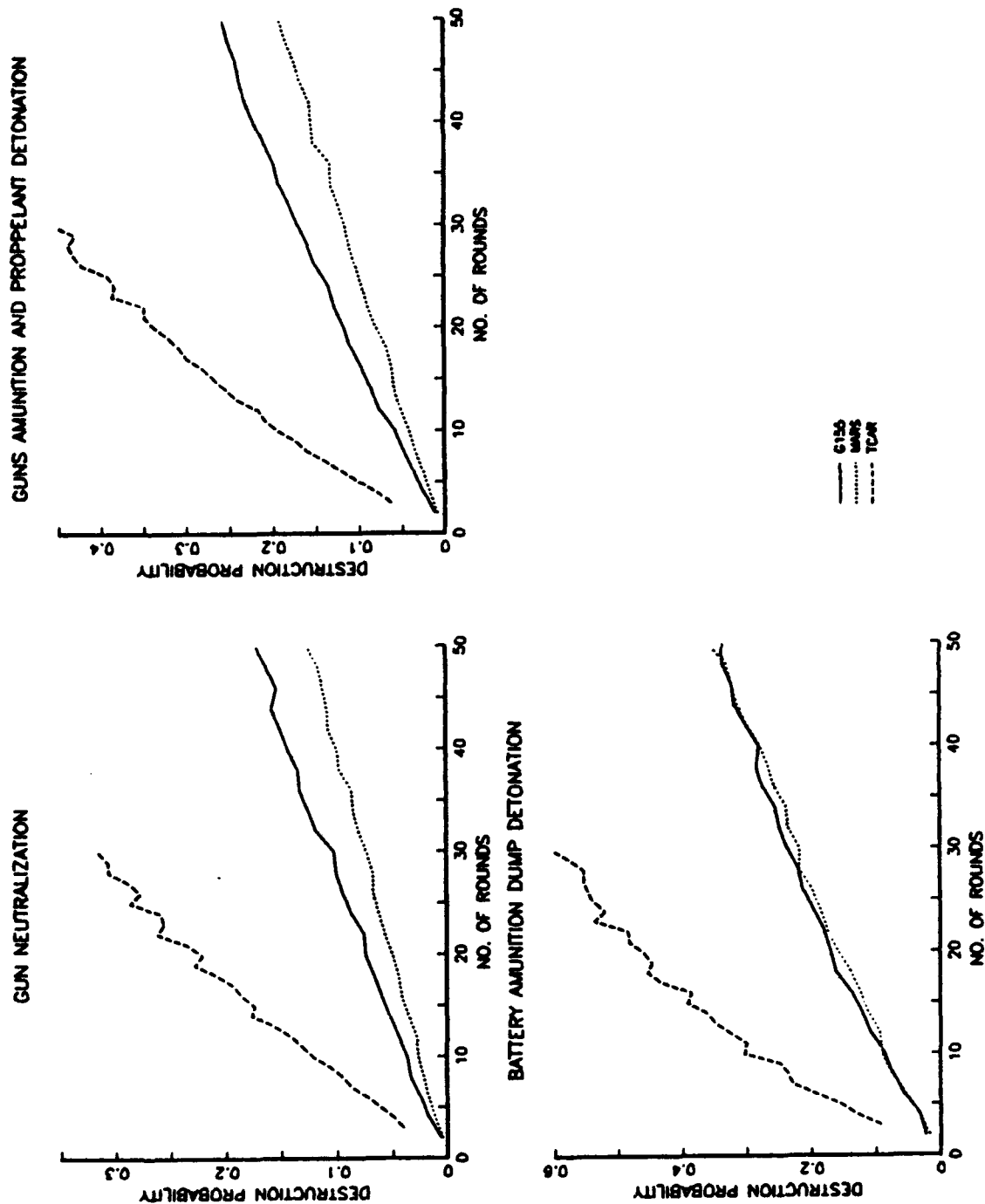


Figure 18. Target No. 4, Artillery Gun Battery, TLE = 50

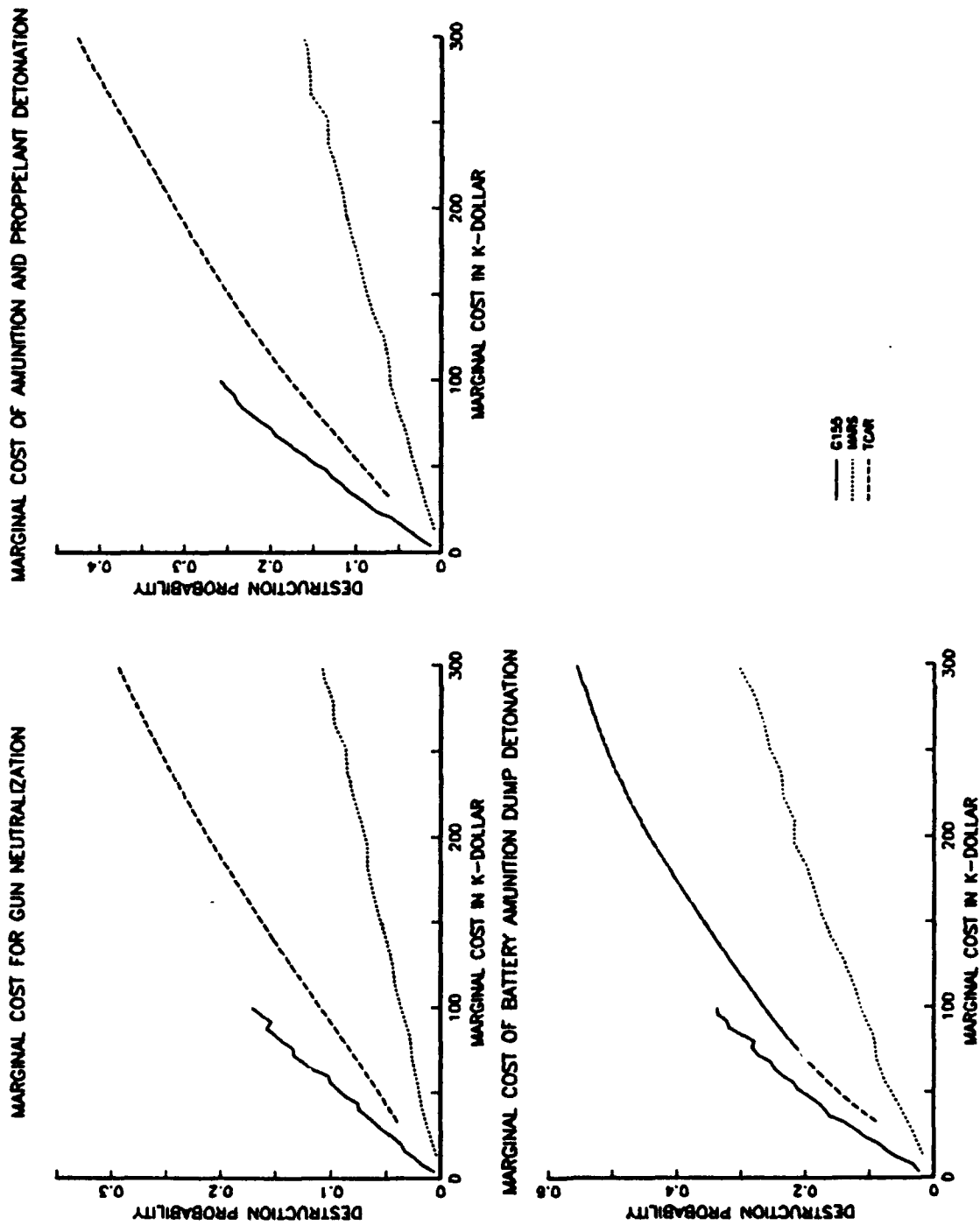


Figure 19. Target No. 4, Artillery Gun Battery, TLE = 50

5. Target Number 5: Soft Vehicles, Logistic Convoy

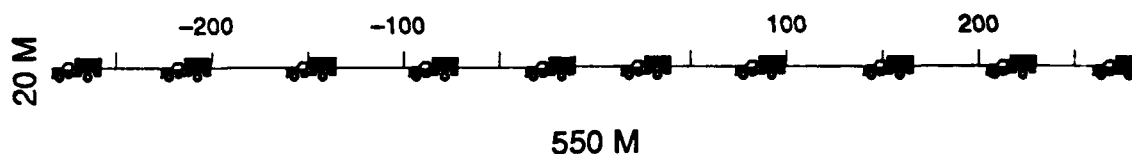


Figure 20. Target No. 5

a. Description

Object: Soft vehicles, trucks carrying troops

Number of units: 10, each carrying 8 troops

Target area size (m): 600 (width) x 25 (depth)

Position: On road, heading X direction

Target location error (one standard deviation):

Standing line and good intelligence 25 (m)

On the move and good intelligence 250 (m) along the road
25 (m) across the road

Passengers are sitting in the trucks, two in the cabin, six in two rows—at the cargo platforms, on two parallel benches.

Ammunition type: Cluster bomblet warhead (or projectile)

Supplementary data:

1. Trucks lethal area—20 sqm
2. Passengers, in sitting position—100 sqm. They are partially protected by the truck, but they are sitting high above ground level.

b. Results

Figure 21 shows the simulation results and marginal cost of damage to trucks and personnel, when the convoy is stationary.

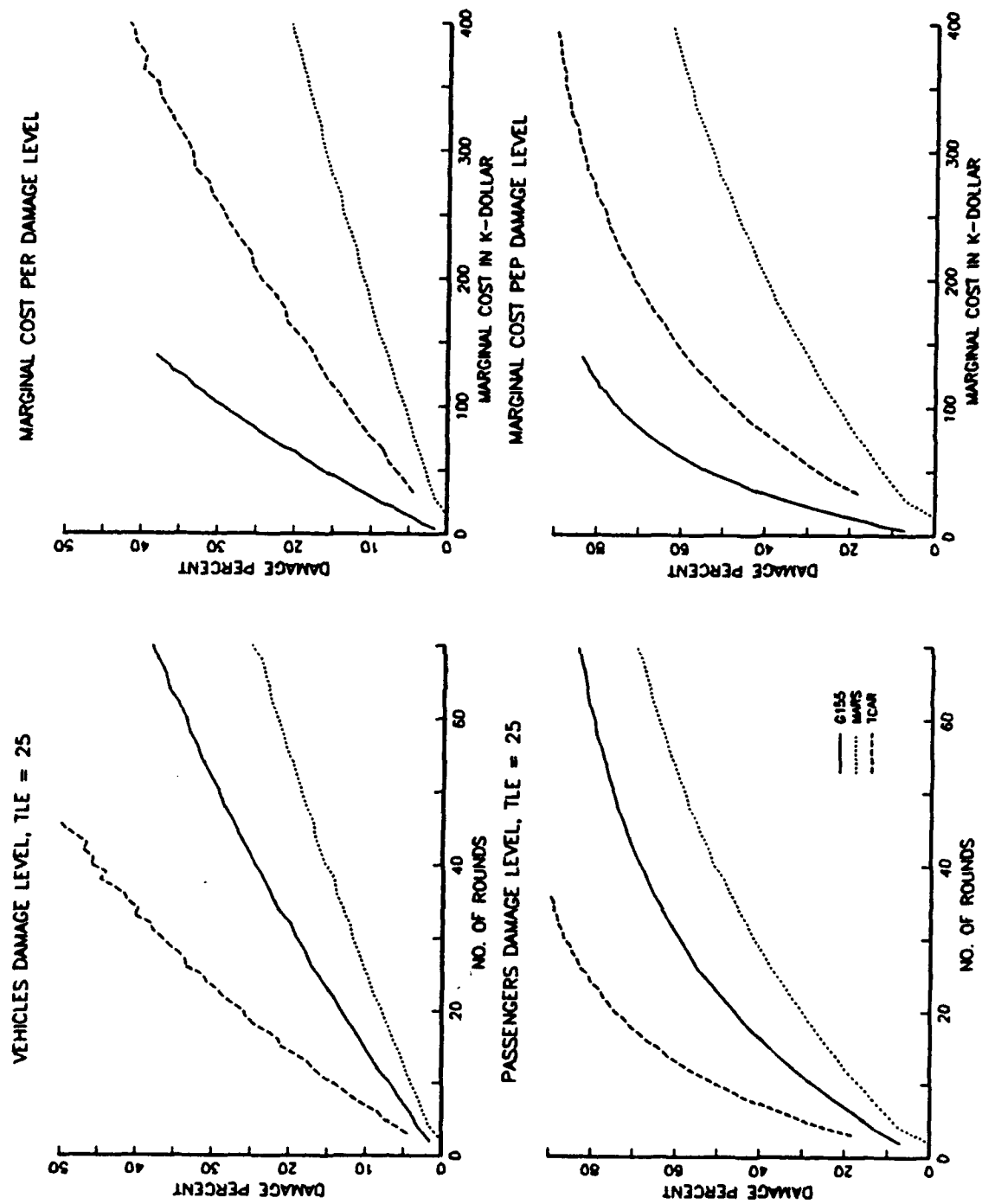


Figure 21. Target No. 5, Vehicle Convoy

Figure 22 shows the simulation results when the convoy is on the move. The two right graphs show the progression of damage level over time.

The following results can be observed from the figures:

1. When the target is stationary, we get results similar to those from previous targets. The highest killing rate is attributed to the TCAR; moreover, the G155 is the most cost-effective.
2. When the target is on the move, the rate of kill becomes a dominant factor. A comparison has been made with a firing battery of G155 (as well as a single gun). The right two graphs of Figure 18 show that all three systems can produce almost the same damage progression through time for both trucks and personnel. The G155 battery was found to be the most cost-effective. This depends on the availability of enough firing units in a busy arena to engage the target. If this is not the case, then the G155 is not effective at all.

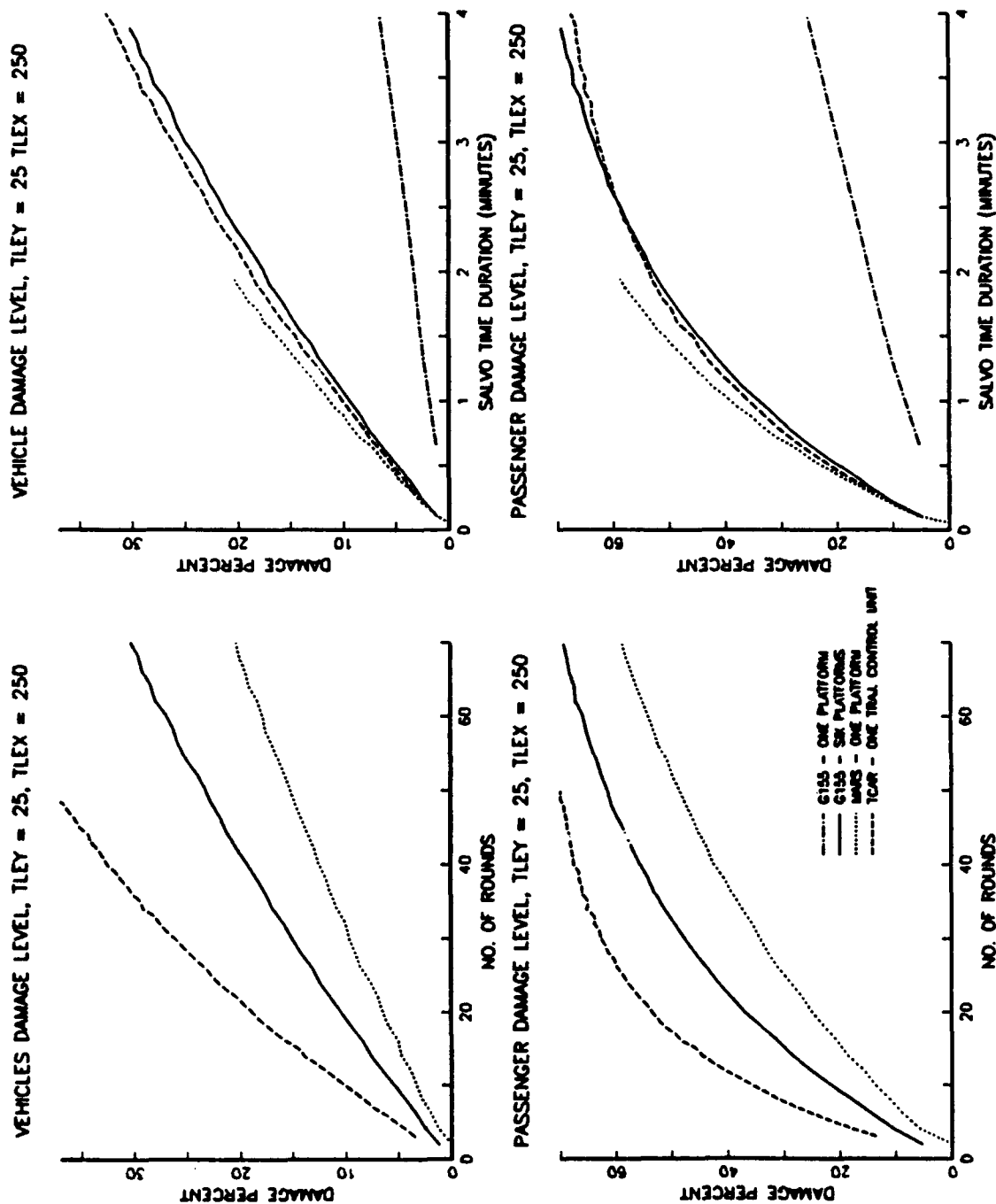


Figure 22. Target No. 5, Vehicle Convoy on the Move

6. Target Number 6: Mixed-Type Target In Defense Position

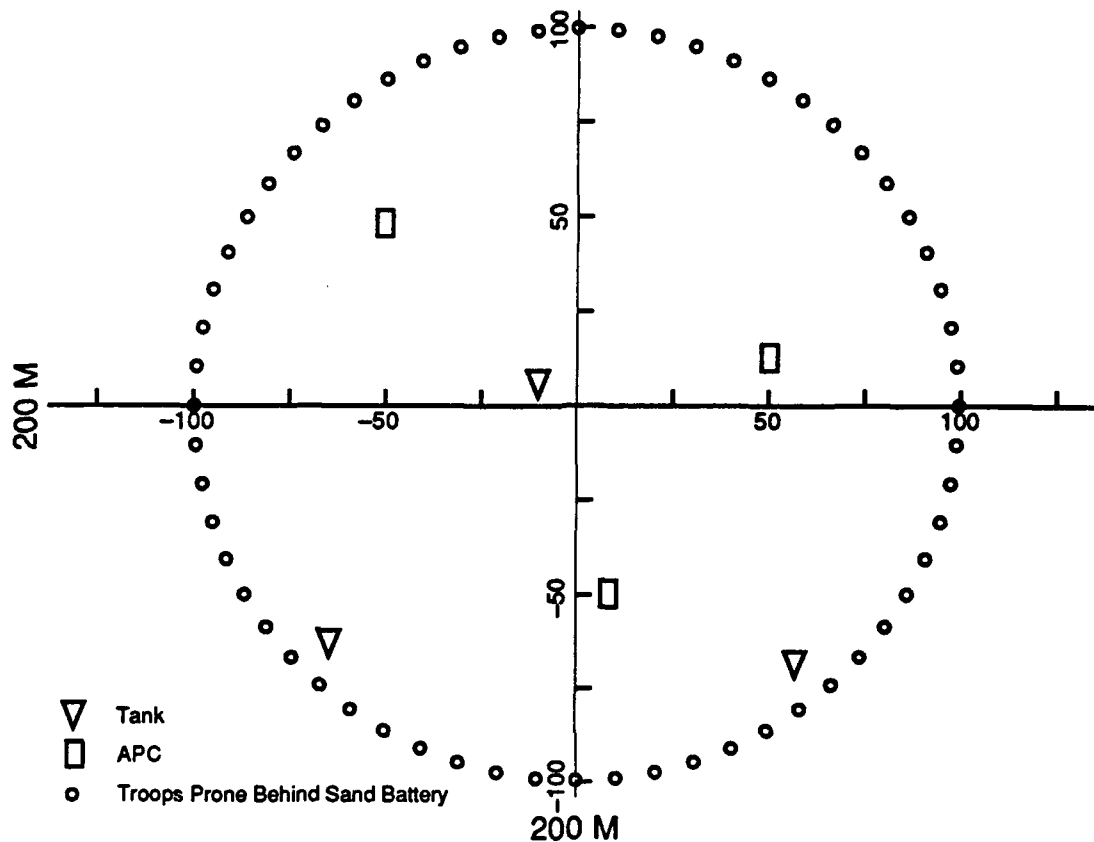


Figure 23. Target No. 6

a. Description

Objects:	Number of Units:
Tanks	3
APCs	3
Personnel	60

Target area size (m): 100 m radius, round fortified site

Position: Tanks and APCs in firing trenches; personnel are prone behind a sand battery surrounding the site.

Target location error (one standard deviation):

Intelligence quality:

Regular	50 m (This is a typically stationary target which is usually detected properly.)
---------	--

Ammunition type:	Cluster bomblet warhead (or projectile) SFM submunition warhead (or projectile)
------------------	--

Supplementary data:

The lethal area for a troop lying behind a sand battery is approximately half that of prone in the open— 40 sqm.

b. Results

Figure 24 shows simulation results and marginal costs of the damage level on tanks. Figure 25 shows the same on APCs. In both figures, the upper two graphs show results of simulations of the three systems that contain SFM submunition warheads. The lower graphs show the same with cluster bomblet warheads.

The following results can be observed from the figures:

1. Rates of kill with SFM submunitions (upper-left graphs) are high for the three systems. TCAR is far superior to the others. MARS and G155 are similar in damage per number of rounds, which means the rate of kill of the MARS is much higher than that of the G155 (because the firing rate of the MARS is much higher).
2. Rates of kill with cluster bomblet warheads (lower-left graphs) show low results for TCAR and poor results for the others.
3. Cost-effectiveness with SFM submunitions (upper-right graphs): TCAR is the most cost-effective, **significantly higher than the G155**. MARS yields very poor results.
4. There is not much difference in cost-effectiveness between the cluster warheads and the SFM warheads, but the comparison is made at a low level of damage (the ordinates scales represent number of destroyed tanks/APCs). Note that the cluster weapon cannot achieve the same high levels of damage as the SFM within a reasonable time.

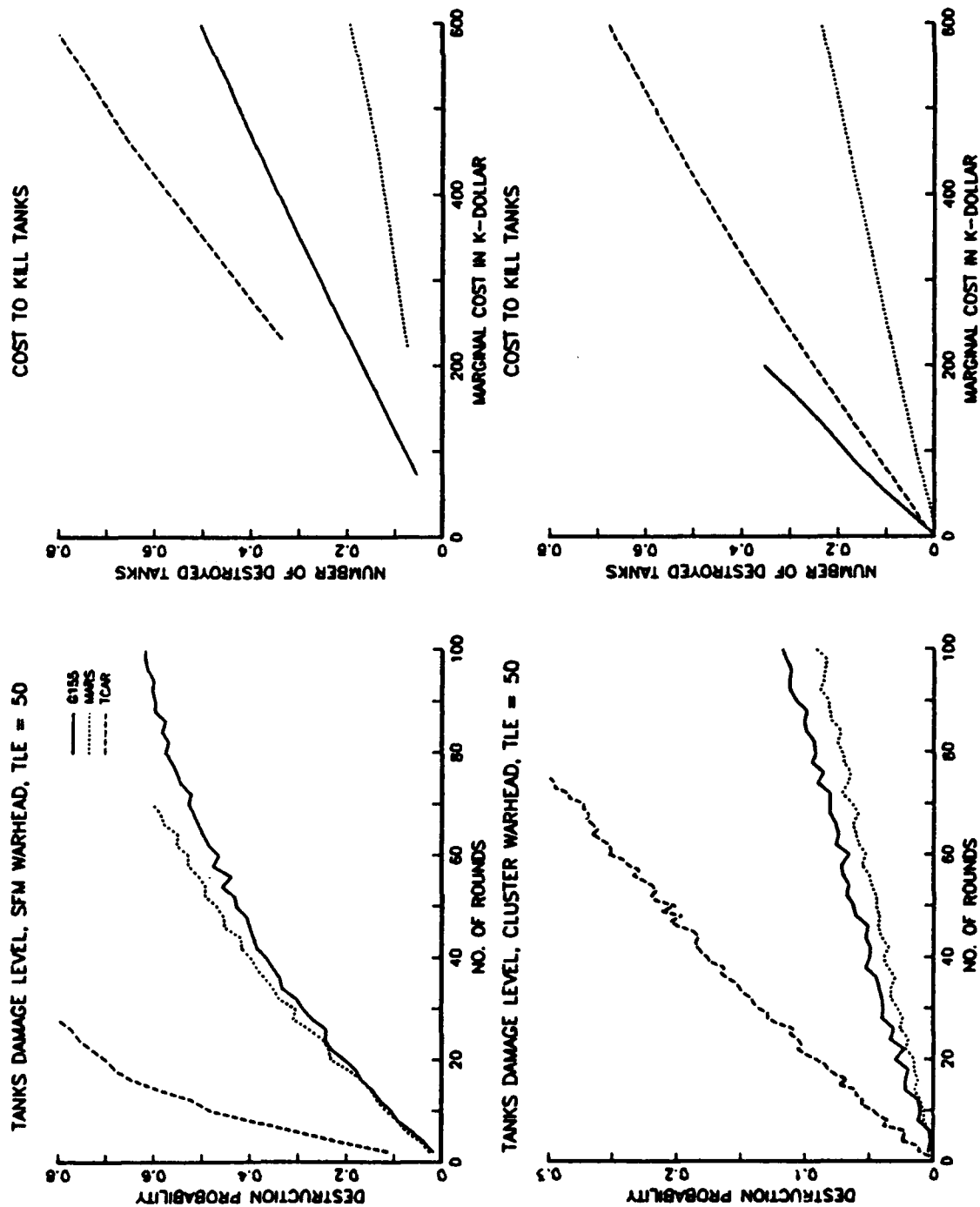


Figure 24. Target No. 6, Tanks, SFM vs. Cluster Warheads

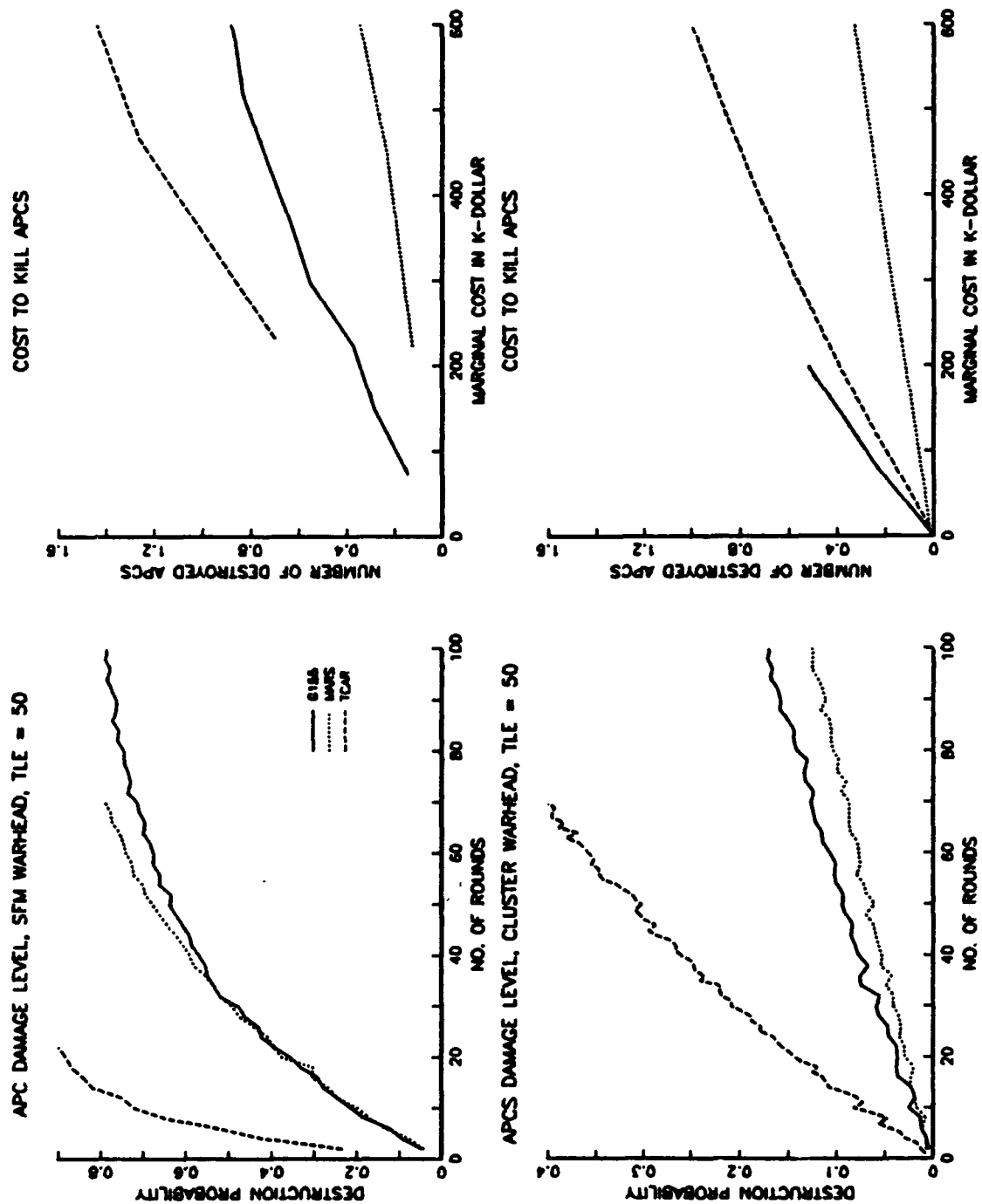


Figure 25. Target No. 6, APCs, SFM vs. Cluster Warheads

5. SFM submunitions: the cost to kill the first tank with TCAR is \$770,000 (\$348,000—APC); with G155 it is \$1,250,000 (\$666,000—APC) and with MARS is \$3,584,000 (\$2,016,000—APC).

Remarks:

- a. The above is not represented in the graphs.
 - b. The first tank to be destroyed, on average, cannot be achieved with a cluster bomblet weapon within a reasonable number of rounds.
6. The cost to kill the second tank with TCAR is \$1,318,000; doing so with MARS or with G155 is not reasonably achievable.
 7. The cost of killing the first armored vehicle (tank/APC) with TCAR is \$232,000. This is a better measure of cost because the effectiveness of the system against tanks depends on the existence of APCs in the target area. If an SFM submunition attacked an APC, it would not be available to attack a tank. In terms of effectiveness against tanks only, this particular submunition is wasteful.

The first armored vehicle for G155 would cost \$407,000 and for MARS would be \$1,120,000.

Troops: The results for prone troops in the target yield similar relationships between the systems as before, so results are not shown on the graphs.

7. Target Number 7: Armor in an Offensive Site

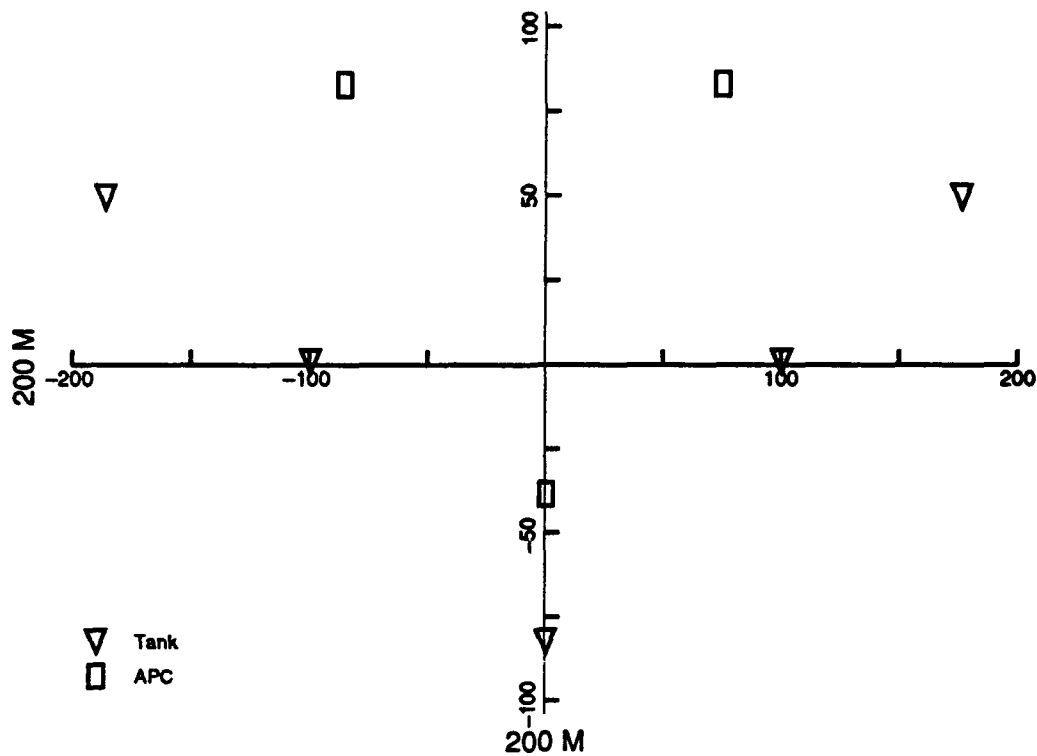


Figure 26. Target No. 7, Armor in an Offensive Site

a. Description

Objects:	Number of Units:
Tanks	5
APC	3
Target area size (m): 360 (width) x 160 (depth)	
Position:	Tanks and APCs in firing sites
Target location error (one standard deviation):	
Intelligence quality	
Regular	50 m

Ammunition type: SFM submunition warhead (or projectile)
Aimpoints were shifted to achieve the best results for each system.

b. Results

Figure 27 shows simulation results and marginal costs of the damage level on tanks and APCs.

The following results can be observed from the figures:

1. The two upper graphs of Figure 27 are for tanks. The lower graphs are for APCs. The difference in the line curvatures can be explained as a result of having only three APC units vs. five tanks. The marginal effectiveness and cost decrease as the remaining number of live targets becomes small.
2. TCAR has a far higher advantage over the other two systems in kill rate. G155 has an extremely low kill rate.
3. TCAR has the best cost-effectiveness for tanks and equal cost-effectiveness compared to G155 for APCs.
4. The cost to kill the first tank with TCAR is \$928,000 (\$694,000—APC), with G155 is \$1,665,000 (592,000—APC), and with MARS is \$4,032,000 (\$1,792,000—APC).
5. The cost to kill the first armored vehicle (tank/APC) with TCAR is \$348,000, with G155 \$407,000, and with MARS \$1,232,000.

8. Target Number 8: Artillery Weapon with SFM Submunition as an Anti-Tank Weapon

The target is a single tank positioned in the center of the target area. This is an attempt to test the SFM submunition when delivered to a target by means of an artillery carrier and used as a pinpoint accurate anti-tank weapon. The question is, can the weapon replace the anti-tank missile?

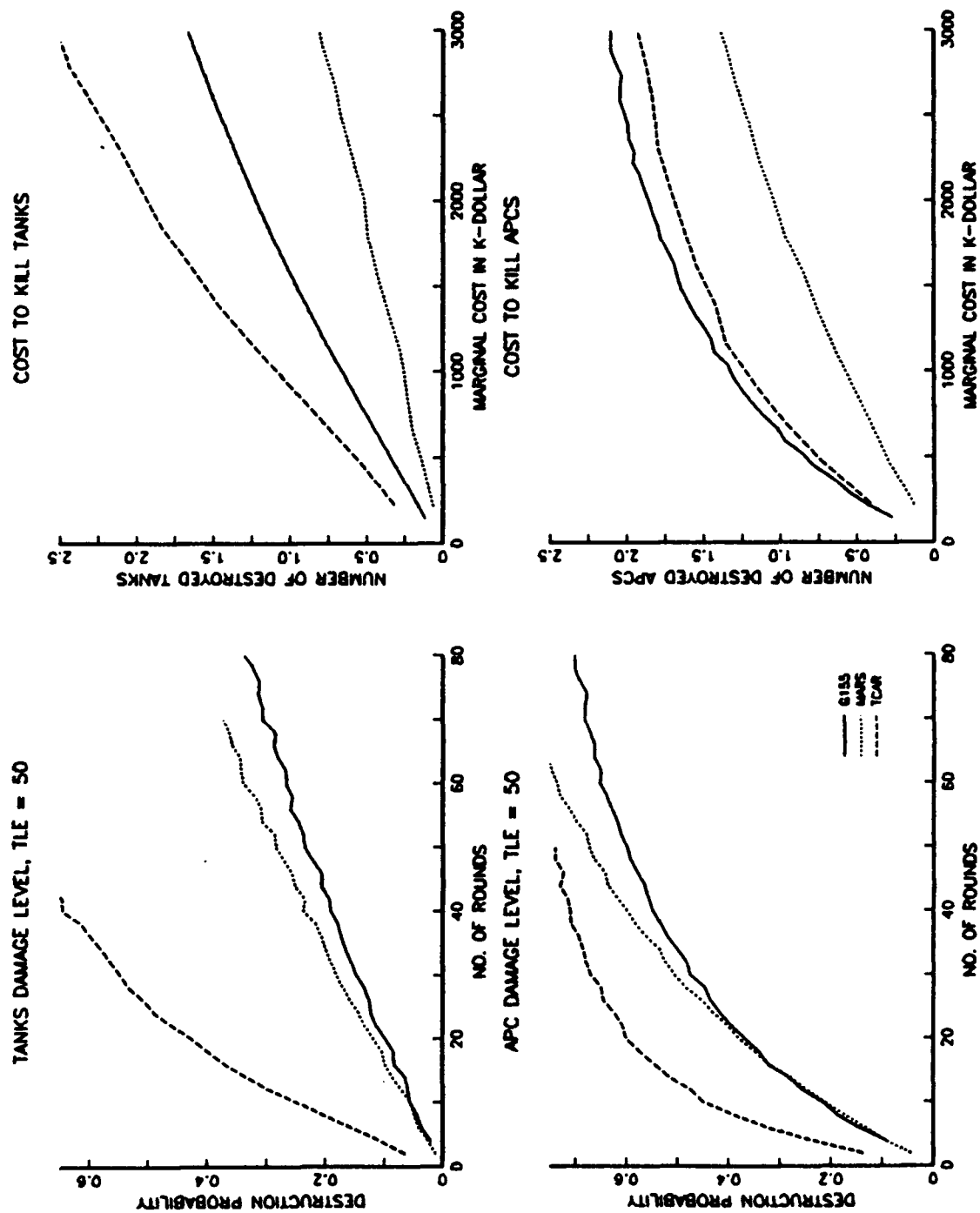


Figure 27. Target No. 7, SFM Warhead

Looking at the left graphs of Figure 28, we can conclude that, of the three systems we are considering, the TCAR is the only feasible system. It can achieve a 50 percent kill probability with 9 to 12 rockets with TLE of 25 to 50, respectively. However, the costs to achieve a 50 percent kill probability are between \$1,000,000 and \$1,300,000. Figure 29 shows the marginal cost of TCAR for TLE 25 and 50 m, in larger scale.

The simple answer to our question is, definitely, the SFM cannot replace anti-tank missiles because it more expensive and less rapid.

It must be understood that when a target contains many objects, the stochastic process is in play. That is, in a densely populated target area, if an artillery weapon misses object *a*, it is probable that it will instead hit object *b*, thereby accomplishing its mission (the probability rising with the object/density of the target).

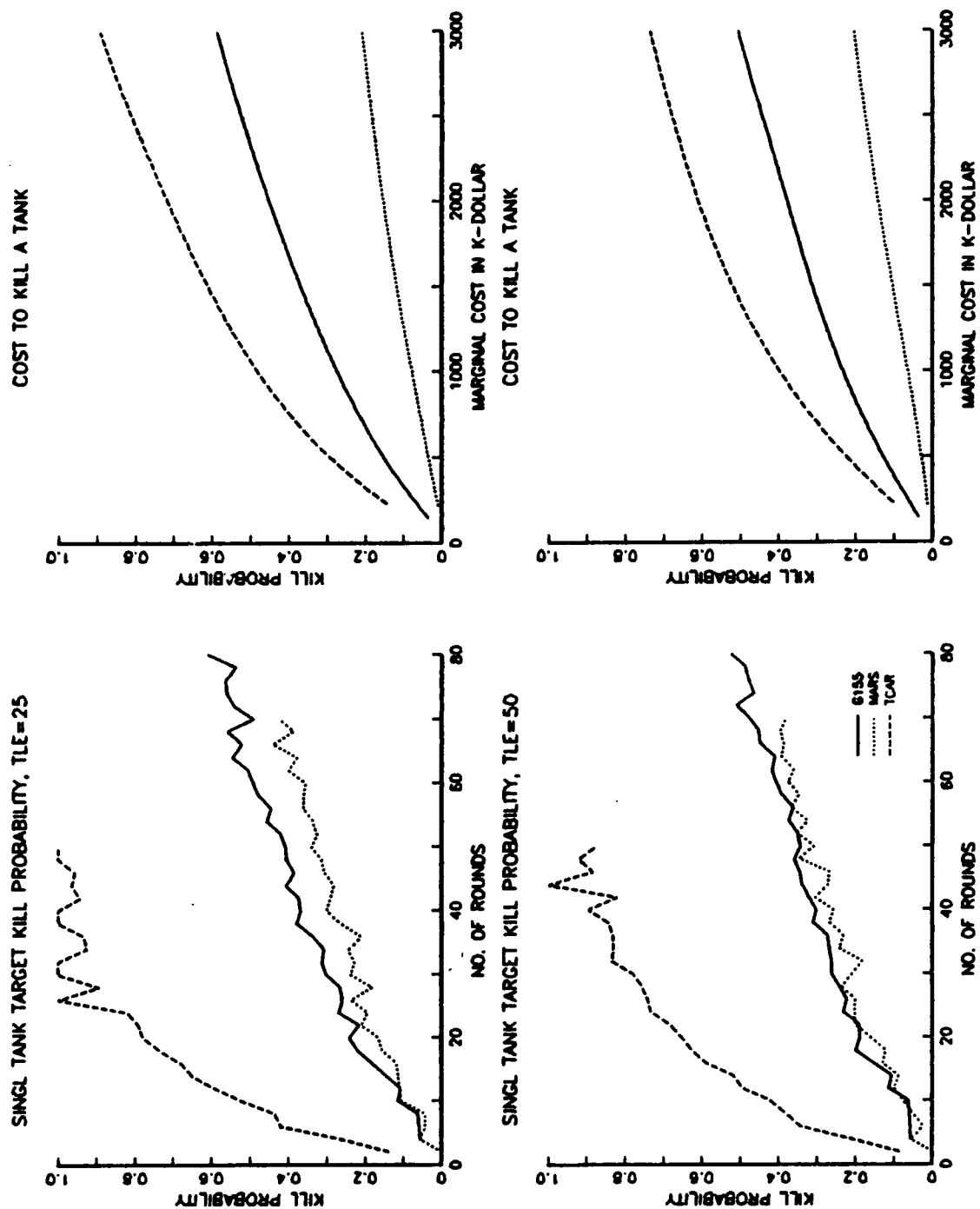


Figure 28. Target No. 8, SFM as an Anti-Tank Weapon

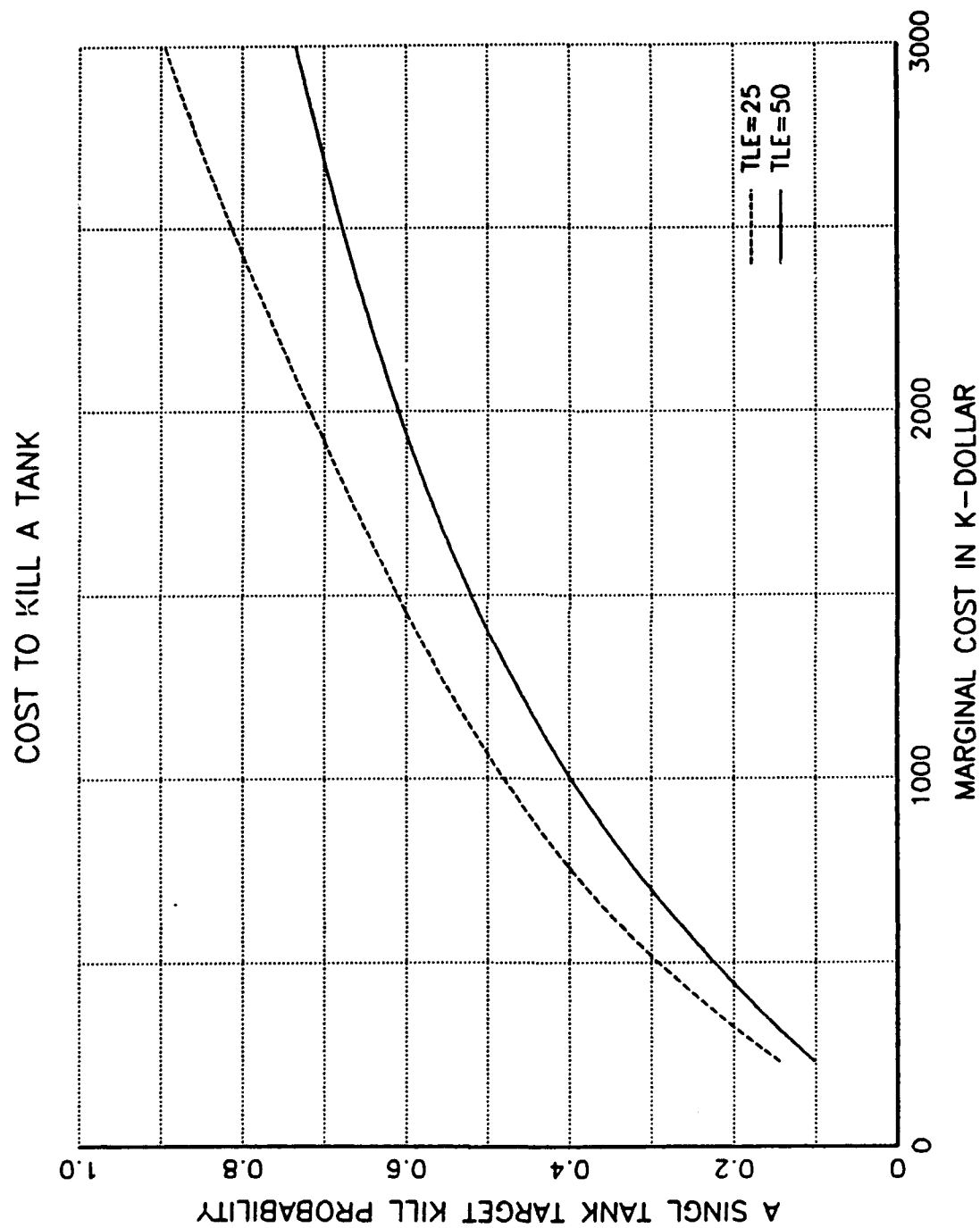


Figure 29. Target No. 8, TCAR with SFM Warhead as an Anti-Tank Weapon

IV. CONCLUSIONS AND RECOMMENDATIONS

The TCAR, as a version of a modern artillery rocket system, has all the artillery rocket system's advantages. However, by enhancing accuracy, a breakthrough in artillery concepts has been created. It is no longer a purely statistical weapon—it both is accurate and has massive kill capabilities that did not exist before.

A. EFFECTIVENESS AND MARGINAL COST

With a cluster bomblet warhead:

- TCAR is capable of performing the highest rate of kill, far above the others, at a relatively affordable cost as compared to tube artillery.
- Tube artillery is the most cost-effective among the three systems. The TCAR is a close second, and MARS is the least cost-effective (far below).
- A battery of 155 mm howitzer guns will accomplish all missions better than a free-flight rocket system.

With an SFM warhead:

- The TCAR is the only system suitable for this kind of submunition. One must consider the difficulties of accommodating "smart" submunitions into projectiles. The severe launching shocks can damage the submunition and moderate performances (rate of kill/range) cause the G155 to be unsuitable for carrying "smart" submunitions. The end results are not worth the technological difficulties required to develop this type of weapon. Furthermore, the MARS capabilities are poor. In this regard, MARS carrying SFM is entirely infeasible.

B. ACCURACY

Since the TCAR's accuracy does not depend on the range (to a limit), it has a longer maximum range than any other known artillery weapon. It

can hit targets located deep in an opponent's territory or engage a wider frontier section.

C. RECOMMENDATIONS

Based on the analysis of this thesis, the author recommends that IMI Ltd. enter into full-scale development of the TCAR. The system is unique, so it has a high likelihood of being acquired.

This thesis provides a set of programs which can be used to evaluate damage assessment on more sets of targets with a variety of artillery system versions and updated real data. The tools developed here can be used to generate input data for some well-known and frequently used combat analysis programs.

The analysis shows a high sensitivity of results to TLE. When it becomes large, the effectiveness decreased very rapidly. It must be emphasized that all the impressive qualities of the TCAR represented in this thesis depend on the availability of a real-time, accurate intelligence system—one that provides the firing unit with information about enemy locations and one that observes the target continuously, giving reports in real time about the target's condition and the firing results. Without high-quality and rapid intelligence, the potential accuracy and lethality of the TCAR is wasted. To accomplish this, it would be necessary to integrate into the firing unit some type of a Remotely Piloted Vehicle (RPV) to be launched by, controlled by, and report directly to the firing unit.

APPENDIX A

NUMERICAL INTEGRATION OF THE PROBABILITY DENSITY FUNCTION OVER AN HOMOGENEOUS TARGET AREA— PROGRAM CODE

PROGRAM MAIN

```
C -----
C Assessment of damage level an homogeneous target subjected to
C Artillery fire of cluster bomblet projectiles or artillery
C rockets.
C The program prints, as output, the probability of a target
C (area) element to be destroyed by a salvo of n rockets.
C -----
C INDICES: Y - RANG, X - CROSS RANGE, T - TARGET, B - BIAS
C P - PRECISION
C -----
C PK1-The probability to kill a target element by a single round
C PKN-The probability to kill a target element by a salvo of N
C round
C XT, YT - Target coordinates
C XB, YB - Salvo bias coordinates
C AX, AY - Halves of rectangle target dimensions
C DXT, DYT - Area elements of the target
C DXB, DYB - Area elements of the bias coordinates set
C MAE - Mean area of effectiveness.
C NDXT, NDYT - Target number of segments
C NDXB, NDYB - Bias coordinates number of segments
C SIGMXP, SIGMYP - Precision, standard deviation of the rounds
C SIGMXB, SIGMYB - Accuracy, standard deviation of the salvo
C bias.
C N - Number of rounds in the salvo
C -----
C$INCLUDE: 'SYSTEM.DEF'
C$INCLUDE: 'TARGET.DEF'
C @@@
C      INCLUDE 'SYSTEM DEF'
C      INCLUDE 'TARGET DEF'
C      OPEN ( UNIT=1, FILE='SYSTEM.DTA', STATUS='OLD')
C      OPEN ( UNIT=2, FILE='TARGET.DTA', STATUS='OLD')
C      OPEN ( UNIT=3, FILE='TARGET.OUT', STATUS='OLD')
C @@@
C      OPEN ( UNIT=1, FILE='/SYSTEM DATA', STATUS='OLD')
C      OPEN ( UNIT=2, FILE='/TARGET DATA', STATUS='OLD')
C
C      READ (1 , *) N, SIGMXP, SIGMYP, SIGMXB, SIGMYB, MAE
```



```

      READ (2 , *) AX, AY, NDXT, NDYT, NDXB, NDYB
      CALL SUBTARGET
      STOP
      END
C -----
      SUBROUTINE SUBTARGET
C
C -----
      REAL DP, DB, DXT, DYT, DXB, DYB, EAT, CDF, XB, YB, XT, YT
      REAL PX1, PKN, G(30,30), GA(30,30), F(30,30), PKTN(10,10)
      INTEGER I, J, K, L
C$INCLUDE: 'SYSTEM.DEF'
C$INCLUDE: 'TARGET.DEF'
C @@@
      INCLUDE 'SYSTEM DEF'
      INCLUDE 'TARGET DEF'
      OPEN ( UNIT=3, FILE='/TARGET OUT', STATUS='OLD')
C
      DP = 2*3.14159*SIGMXP*SIGMYP
      DB = 2*3.14159*SIGMXB*SIGMYB
      DXT = 2*AX / NDXT
      DYT = 2*AY / NDYT
      DXB = 3*SIGMXB / NDXB
      DYB = 3*SIGMYB / NDYB
C
      EAT = 0.
      CDF = 0.
C
      DO 100 I=1,NDXB
        DO 200 J=1,NDYB
          GA(I,J) = 0.
          XB = DXB/2. +(I-1)*DXB
          YB = DYB/2. +(J-1)*DYB
          DO 300 K=1, NDXT
            DO 400 L=1, NDYT
              XT = DXT/2. +(K-1)*DXT - AX
              YT = DYT/2. +(L-1)*DYT - AY
              PX1=(MAE/DP)*EXP(((XB-XT)/SIGMXP)**2
&              +((YB-YT)/SIGMYP)**2)/(-2.))
              PKTN(K,L) = 1-(1-PX1)**N
              GA(I,J) = GA(I,J) + PKTN(K,L)
            400      CONTINUE
          300      CONTINUE
          G(I,J) = GA(I,J)*DXT*DYT
          F(I,J) = (1./DB)*DXB*DYB*EXP((XB/SIGMXB)**2
&          + (YB/SIGMYB)**2)/(-2.))
          EAT = EAT + G(I,J)*F(I,J)
          CDF = CDF + F(I,J)
        200      CONTINUE
      100      CONTINUE

```

```

      PKN = EAT / (AX*AY)
      WRITE (3,10) PKN, EAT, 4*CDF, N ,MAE, AX, AY
      WRITE (3,20) SIGMXP, SIGMYP, SIGMXB, SIGMYB
      WRITE (3,30) NDXT, NDYT, NDXB, NDYB
      WRITE (*,10) PKN, EAT, 4*CDF, N ,MAE, AX, AY
      WRITE (*,20) SIGMXP, SIGMYP, SIGMXB, SIGMYB
      WRITE (*,30) NDXT, NDYT, NDXB, NDYB
10  FORMAT (' DESTRUCTION PROBABILITY= ',F6.4 ,
& /' DESTROYED AREA (SQM)=' ,F8.0 ,/ ' PDF INTEGRAL=' ,F6.4 ,
& /' NO. OF ROUNDS=' ,I4 ,/ ' MEAN AREA OF EFFECTIVENESS',
& ' (SQM)=' , F8.1 , /' TARGET HALF WIDTH (M)=' ,F7.2 ,
& /' TARGET HALF LENGTH (M)=' ,F7.2 )
20  FORMAT(' PRECISION CR STANDARD DEVIATION (M)=' ,F5.1 ,
& /' PRECISION RANGE STANDARD DEVIATION (M)=' ,F5.1 ,
& / ' BIAS RANGE STANDARD DEVIATION (M)=' ,F5.1 ,
& / ' BIAS CRROS RANGE STANDARD DEVIATION (M)=' ,F5.1 )
30  FORMAT ( ' NO. OF SIGMENTS ON TARGET ' ,F4.0,'X',F4.0,/
& ' NO. OF SIGMENTS ON THE OPEN AREA ' ,F4.0,'X',F4.0 /)
      RETURN
      END
C
C -----
INCLUDE FILES
SYSTEM DEF
      REAL SIGMXP, SIGMYP, SIGMXB, SIGMYB, MAE
      INTEGER N
      COMMON/SYSTEM/N, SIGMXP, SIGMYP, SIGMXB, SIGMYB, MAE

TARGET DEF
      REAL AX, AY, NDXB, NDYB, NDXT, NDYT
      COMMON/TARGETDEF/ AX, AY, NDXB, NDYB, NDXT, NDYT

```

APPENDIX B

TARGET DAMAGE ASSESSMENT, SIMULATION PROGRAMS CODE

```

PROGRAM MAIN300
C =====
C SIMULATION OF TARGET DAMAGE ASSESSMENT, CLUSTER BOMBLET WAREAHEADS
C =====C
C THE PROGRAM READS SYSTEM AND TARGET DATA. IT CALLS FOR SALVOROND
C SUBROUTINE TO SIMULATE THE DAMAGE LEVEL CAUSED BY FIRING VARIABLE
C ROUNDS IN A SALVO.
C WHILE RECEIVING THE ONE SALVO RESULTS, THE PROGRAM CALLS FOR
C STATISTICS SUBROUTINE THAT CALCULATES CONSECUTIVELY, AVERAGE,
C STANDARD DEVIATIONS AND CONFIDENCE INTERVALS.
C THE PROGRAM STOPS WHEN THE CONFIDENCE INTERVAL FOR 95% CONFIDENCE
C IS REDUCED TO A FIXED RESOLUTION.
C SIMULATION OF 5 TARGET TYPES THAT ARE DEPLOYED IN THE SAME AREA
C CAN BE HANDLED SIMULTANEOUSLY.
C TYPICALLY ANY COMBINATION OF 5 CAN BE CHOSEN OUT OF THE FOLLOWING:
C TANK, APC, ARTILLERY GUN, SOFT VEHICLE, STANDING TROOPS, PRONE
C TROOPS, LAYING TROOPS AND CROUCHING (IN FOXHOLES ) TROOPS.
C
C AL(I)...LETHAL AREA OF A BOMBLET ON TARGET TYPE I
C AP...BOMBLET PATTERN ELLIPSOID, CROSS RANGE RADIUS
C BP...BOMBLET PATTERN ELLIPSOID, RANGE RADIUS
C NBOM...NUMBER OF BOMBLETS IN ONE ROUND.
C TD(I)...NUMBER OF TARGET TYPE I ELEMENTS THAT WERE DESTROYED.
C RESOL...RESOLUTION
C NEXT(I,J)...LINK LIST MATRIX.
C
C -----
C$INCLUDE: 'CTARGET.DEF'
C$INCLUDE: 'CSEED.DEF'
C$INCLUDE: 'CSYSTEM.DEF'
C @@@
C      INCLUDE 'CTARGET DEF'
C      INCLUDE 'CSEED DEF'
C      INCLUDE 'CSYSTEM DEF'
C
C      INTEGER I, J, M, COUNT, TD(5), NBOM, NEXT(5,100)
C      INTEGER MINSALVO, MAXSALVO, INTERVAL
C      REAL TDAVG(5), TDSTD(5), RESOL(5), CONFINT, AL(5), DMGLEVE(5,3)
C      REAL TLEX, TLEY
C      LOGICAL DONE
C      CHARACTER*8 TTYPE(5)
C
C @@@
C      OPEN ( 1, FILE='/TARGET6 DATA', STATUS='OLD')
C      OPEN ( 2, FILE='/WEAPON DATA', STATUS='OLD')
C      OPEN ( 3, FILE='/MAIN300 OUT', STATUS='OLD')

```

```

OPEN ( 4, FILE='/CSEED DATA', STATUS='OLD' )
OPEN ( 5, FILE='/MAIN300 LIST', STATUS='OLD')

C
C
READ ( 2, *) SIGXP, SIGYP, SIGXB, SIGYB, RATE, AP, BP, NBOM
READ ( 2, *) ( AL(I), I=1, 5 )
READ ( 2, *) NPLAT, MINSALVO, MAXSALVO, INTERVAL, LTIME
READ ( 2, *) NAPX, NAPY, DX, DY, TLEX, TLEY
READ ( 4, *) ( SEED(I), I=1,6)

C
DATA RESOL / .1, .1, .1, .1, .6 /

C
SIGXB = SQRT(SIGXB**2 + TLEX**2)
SIGYB = SQRT(SIGYB**2 + TLEY**2)

C
DO 100 I=1, 5
  READ (1, *) N(I) , TTYPE(I), ( DMGLEVE(L(I,M), M = 1, 3 )
  DO 110 J=1, N(I)
    READ (1, *) X(I,J), Y(I,J)
    NEXT(I, J) = J + 1
110  CONTINUE

C
  IF ( N(I) .GT. 0 ) NEXT(I, N(I)) = 0
  PK1(I) = 1 - ( 1 - AL(I) / ( 3.14159*AP*BP ) )**NBOM
100 CONTINUE

C
WRITE (5, 40) SIGXB, SIGYB, NAPX, DX, TLEX, TLEY

C
DO 200 NSALVO = MINSALVO, MAXSALVO, INTERVAL
  COUNT = 0
  DO 201 I=1, 5
    TD(I) = 0
    TDAVG(I) = 0.0
201  CONTINUE

C
C
300  CONTINUE
  PRINT*, 'FROM MAIN COUNT=',COUNT, 'AP=',AP, 'BP=',BP
  DONE = .TRUE.
  CALL SALVOROUND ( NEXT, NSALVO, TD )
  DO 350 I = 1, 5
    IF ( N(I) .GT. 0 ) THEN
      CALL STATISTICS ( COUNT, TD(I), TDAVG(I), TDSTD(I) )
      IF (CONFINT(COUNT,TDSTD(I)).GT.RESOL(I))DONE =.FALSE.
      IF ( COUNT .LT. 3 ) DONE = .FALSE.
    ENDIF
350  CONTINUE
    COUNT = COUNT + 1
  IF ( .NOT. DONE ) GO TO 300

C
C
WRITE (3, *)
WRITE (3, *) ' SALVO=',NSALVO , ' REPEAT=',COUNT
WRITE (3,10) ( TTYPE(I), TDAVG(I), I = 1, 5 )
WRITE (3,20) ( TTYPE(I), TDAVG(I)/(N(I)+.001), I = 1, 5)
WRITE (5,30) NSALVO,((TDAVG(I)/(N(I)+.001))*100, I = 1, 5)

```

```

200 CONTINUE
C      WRITE (*, *)  'PK1(I)= ', ( PK1(I), I=1,5 ), ' REPEAT=',COUNT
C
C
C
10  FORMAT (/,5(1X,A7,'=',F4.1) )
20  FORMAT ( 5(1X,A7,'=',F4.3) )
30  FORMAT ( 1X,I4,5(1X,F4.1) )
40  FORMAT ( ' SIGXB=',F7.2, ' SIGYB=',F7.2, ' NAPX=',I2, ' DX=',F6.1,
& ' TLEX=',F6.2, ' TLEY=',F6.2 )
      STOP
      END

```

```

      SUBROUTINE SALVOROUND( NEXTMATRIX, NSALVO, SCORE )
C -----
C SIMULATION OF DAMAGE LEVEL WHEN FIRING A SALVO OF FIXED ROUNDS
C -----
C
C THE SUBROUTINE ACCEPTS THE TARGET ELEMENTS LINKED BY A LINK LIST
C MATRIX. SAMPLE A BIAS ERROR. SAMPLE PRECISION ERROR. SEARCH FOR
C A TARGET ELEMENT IN THE PATTERN ELLIPSOID. IF FOUND, IT IS
C ELIMINATED FROM THE LIST. COUNT NUMBER OF ELIMINATIONS.
C WHEN SALVO PREDETERMINED ROUNDS WHERE COMPLETED, RETURNS.
C
C -----
C
CINCLUDE: 'CTARGET.DEF'
CINCLUDE: 'CSEED.DEF'
CINCLUDE: 'SYS100.DEF'
C @@@
      INCLUDE 'CSYSTEM.DEF'
      INCLUDE 'CTARGET.DEF'
      INCLUDE 'CSEED.DEF'
C @@@
      INTEGER ROUND, I, J, SCORE(5), FIRST(5), PNT, NEXT(5,100)
      INTEGER NEXTMATRIX(5, 100), NSALVO
      REAL TIME, XB, XH, XP, YB, YH, YP, RAN, SPLITX, SPLITY
      LOGICAL FST
C
      CALL RANNUM( 2, SEED(1), 0.0, SIGXB, 0, XB )
      CALL RANNUM( 2, SEED(2), 0.0, SIGYB, 0, YB )
C
      ROUND = 0
      TIME = 0.0
      DO 101 I = 1, 5
        FIRST(I) = 1
        SCORE(I) = 0
        DO 102 J = 1, N(I)
          NEXT(I, J) = NEXTMATRIX(I, J)
        102 CONTINUE
      101 CONTINUE
C
      100 CONTINUE
        ROUND = ROUND + 1
        CALL RANNUM( 2, SEED(3), 0.0, SIGXP, 0, XP )
        CALL RANNUM( 2, SEED(4), 0.0, SIGYP, 0, YP )
        XH = XB + XP
        YH = YB + YP
        IF ( NAPX .GT. 1 ) XH = XH + SPLITX(ROUND, NSALVO, NAPX, DX)
        IF ( NAPH .GT. 1 ) YH = YH + SPLITY(ROUND, NSALVO, NAPH, DY)
        DO 300 I = 1, 5
          IF ( N(I) .GT. 0 ) THEN
            150 CONTINUE
            IF ( FIRST(I) .GT. 0 ) THEN
              FST = .FALSE.
              J = FIRST(I)
              WRITE(3,*) 'FROM SALVO 1 ROUND=',ROUND,' J=',J
              IF((((XH-X(I,J))/AP)**2+((YH-Y(I,J))/BP)**2).LT.1.)THEN
                CALL RANNUM( 1, SEED(5), 0.0, 1.0, 0, RAN )

```

```

        IF ( RAN .LT. PK1(I) ) THEN
            FIRST(I) = NEXT(I,J)
            SCORE(I) = SCORE(I) + 1
            FST = .TRUE.
        ENDIF
    ENDIF
    IF ( FST ) GO TO 150
    PNT = FIRST(I)

C
C 200
C
    200      IF ( NEXT(I, J) .GT. 0 ) THEN
                J = NEXT(I,J)
                IF((((XH-X(I,J))/AP)**2+((YH-Y(I,J))/BP)**2).LT.1.)THEN
                    CALL RANUM( 1, SEED(5), 0.0, 1.0, 0, RAN )
                    IF ( RAN .LT. PK1(I) ) THEN
                        NEXT(I,PNT) = NEXT(I,J)
                        SCORE(I) = SCORE(I) + 1
                    ELSE
                        PNT = J
                    ENDIF
                ELSE
                    PNT = J
                ENDIF
            GO TO 200
        ENDIF
    ENDIF
    300      CONTINUE

C
C
    IF ( ROUND .LT. NSALVO ) GO TO 100

C
    RETURN
    END

```

INCLUDE FILES

CSYSTEM DEF

C

```

        INTEGER NAPX, NAPI
        REAL SIGXP, SIGYP, SIGXB, SIGYB, RATE, AP, BP, PK1(5), DX, DY
        COMMON /SYSTEM/ SIGXP, SIGYP, SIGXB, SIGYB, RATE, AP, BP, PK1,
        & NAPX, NAPI, DX, DY

```

C

```

C PK1(I)...PROBABILITY TO KILL A TARGET TYPE I IN THE PATTERN OF ONE
C WARHEAD
C RATE...RATE OF FIRE OF ONE PLATFORM
C NAPX, NAPI... NUMBER OF AIMPOINTS ON THE TARGET
C DX, DY ... MAX. DISTANCE OF AIMPOINT DEVIATION FROM THE TARGET CENTER
C

```

CTARGET DEF

C

```

        INTEGER N(5), NPLAT

```

```
REAL X(5,100), Y(5,100), LTIME  
COMMON/TARGET/ X, Y, N, NPLAT, LTIME
```

C

CSEED DEF

C

```
INTEGER SEED(8)  
COMMON/SEED SET/ SEED
```

C

PROGRAM MAINTIME

```

C -----
C SIMULATION OF TARGET DAMAGE ASSESSMENT, CLUSTER BOMBLET WAREAHEADS
C IN THIS SIMULATION LETHAL AREA DECREASES AS A FUNCTION OF SALVO
C TIME DURATION.
C -----
C
C THE PROGRAM READS SYSTEM AND TARGET DATA. IT CALLS FOR SALVOROND
C SUBROUTINE TO SIMULATE THE DAMAGE LEVEL CAUSED BY FIRING VARIABLE
C ROUNDS IN A SALVO.
C WHILE RECEIVING THE ONE SALVO RESULTS, THE PROGRAM CALLS FOR
C STATISTICS SUBROUTINE THAT CALCULATE CONSECUTIVELY, AVERAGE,
C STANDARD DEVIATIONS AND CONFIDENCE INTERVALS.
C THE PROGRAM STOPS WHEN THE CONFIDENCE INTERVAL FOR 95% CONFIDENCE
C IS REDUCED TO A FIXED RESOLUTION.
C SIMULATION OF 5 TARGET TYPES THAT ARE DEPLOYED IS THE SAME AREA
C CAN BE HANDLED SIMULTANEOUSLY.
C TYPICALLY ANY COMBINATION OF 5 CAN BE CHOSEN OUT OF THE FOLLOWING:
C TANK, APC, ARTILLERY GUN, SOFT VEHICLE, STANDING TROOPS, PRONE
C TROOPS, LAYING TROOPS AND CROUCHING (IN FOXHOLES ) TROOPS.
C
C AL(I)...LETHAL AREA OF A BOMBLET ON TARGET TYPE I
C AP...BOMBLET PATTERN ELLIPSOID, CROSS RANGE RADIUS
C BP...BOMBLET PATTERN ELLIPSOID, RANGE RADIUS
C NBOM...NUMBER OF BOMBLETS IN ONE ROUND.
C TD(I)...NUMBER OF TARGET TYPE I ELEMENTS THAT WHERE DESTROYED.
C RESOL...RESOLUTION
C NEXT(I,J)...LINK LIST MATRIX.
C
C -----
C$INCLUDE: 'CTARGET.DEF'
C$INCLUDE: 'CSEED.DEF'
C$INCLUDE: 'C400SYST.DEF'
C @@@
C     INCLUDE 'CTARGET DEF'
C     INCLUDE 'CSEED DEF'
C     INCLUDE 'C400SYST DEF'
C
C     INTEGER I, J, M, COUNT, TD(5), NEXT(5,100)
C     INTEGER MINSALVO, MAXSALVO, INTERVAL
C     REAL TDAVG(5), TDSTD(5), RESOL(5), CONFINIT
C     LOGICAL DONE
C     CHARACTER*8 TTYPE(5)
C
C     OPEN ( 1, FILE='TARGET.DTA', STATUS='OLD')
C     OPEN ( 2, FILE='SYSTEM.DTA', STATUS='OLD')
C     OPEN ( 3, FILE='SYSTEM.OUT', STATUS='OLD')
C     OPEN ( 4, FILE='SEED.DTA', STATUS='OLD' )
C @@@
C     OPEN ( 1, FILE='/TARGET1 DATA', STATUS='OLD')
C     OPEN ( 2, FILE='/WEAPON DATA', STATUS='OLD')
C     OPEN ( 2, FILE='/CSYSTEM DATA', STATUS='OLD')
C     OPEN ( 3, FILE='/TIME OUT', STATUS='OLD')
C     OPEN ( 4, FILE='/CSEED DATA', STATUS='OLD' )
C     OPEN ( 5, FILE='/TIMELIST OUT', STATUS='OLD')
C

```

```

      READ ( 2, *) SIGXP, SIGYP, SIGXB, SIGYB, RATE, AP, BP, NBOM
      READ ( 2, *) ( AL(I), I=1, 5 ),AL0
      READ ( 2, *) NPLAT, MINSALVO, MAXSALVO, INTERVAL, (GAMMA(I),I=1,5)
      READ ( 4, *) ( SEED(I), I=1,6)

C
      DATA RESOL / .8, .8, .8, .8, .8 /
C
      DO 100 I=1, 5
        READ (1, *) N(I) , TTYPE(I)
        DO 110 J=1, N(I)
          READ (1, *) X(I,J), Y(I,J)
          NEXT(I, J) = J + 1
110      CONTINUE
C
        IF ( N(I) .GT. 0 ) NEXT(I, N(I)) = 0
100      CONTINUE
C
      DO 200 NSALVO = MINSALVO, MAXSALVO, INTERVAL
        COUNT = 0
        DO 201 I=1, 5
          TD(I) = 0
          TDAVG(I) = 0.0
201      CONTINUE
C
C
300      CONTINUE
C
        PRINT*, 'FROM MAIN COUNT=',COUNT, 'AP=',AP, 'BP=',BP
        DONE = .TRUE.
        CALL SALVOTIME( NEXT, NSALVO, TD )
        DO 350 I = 1, 5
          IF ( N(I) .GT. 0 ) THEN
            CALL STATISTICS ( COUNT, TD(I), TDAVG(I), TDSTD(I) )
            IF (CONFINT(COUNT,TDSTD(I)).GT.RESOL(I))DONE =.FALSE.
            IF ( COUNT .LT. 3 ) DONE = .FALSE.
          ENDIF
350      CONTINUE
          COUNT = COUNT + 1
          IF ( .NOT. DONE ) GO TO 300
C
C
        WRITE (3, *)
        WRITE (3, *) ' SALVO=',NSALVO , ' REPEAT=',COUNT
        WRITE (3 ,10) ( TTYPE(I), TDAVG(I), I = 1, 5 )
        WRITE (3 ,20) ( TTYPE(I), TDAVG(I)/(N(I)+.001), I = 1, 5)
        WRITE (5 ,30) NSALVO,((TDAVG(I)/(N(I)+.001))*100, I = 1, 5)
C
200      CONTINUE
C
C
C
10      FORMAT (/ ,5(1X,A7,'=',F4.1) )
20      FORMAT ( 5(1X,A7,'=',F4.3) )
30      FORMAT ( 1X,I4,5(1X,F4.1) )
      STOP
      END

```

```

SUBROUTINE SALVOTIME( NEXTMATRIX, NSALVO, SCORE )

C =====
C SIMULATION OF DAMAGE LEVEL WHEN FIRING A SALVO OF FIXED ROUNDS
C IN THIS SIMULATION LETHAL AREA IS DECREASED AS FUNCTION OF THE
C SALVO TIME DURATION
C =====
C
C THE SUBROUTINE ACCEPTS THE TARGET ELEMENTS LINKED BY A LINK LIST
C MATRIX. SAMPLE A BIAS ERROR. SAMPLE PRECISION ERROR. SEARCH FOR
C A TARGET ELEMENT IN THE PATTERN ELLIPSOID. IF FOUND, IT IS
C ELIMINATED FROM THE LIST. COUNT NUMBER OF ELIMINATIONS.
C WHEN SALVO PREDETERMINED ROUNDS WHERE COMPLETED, RETURNS.
C
C -----
C
CINCLUDE: 'CTARGET.DEF'
CINCLUDE: 'CSEED.DEF'
CINCLUDE: 'C400SYST.DEF'
C @@@
      INCLUDE 'C400SYST DEF'
      INCLUDE 'CTARGET DEF'
      INCLUDE 'CSEED DEF'
C @@@
      INTEGER ROUND, I, J, SCORE(5), FIRST(5), PNT, NEXT(5,100)
      INTEGER NEXTMATRIX(5, 100), NSALVO
      REAL TIME, XB, XH, XP, YB, YH, YP, RAN, PK1, ALT
      LOGICAL FST

C
      CALL RANNUM( 2, SEED(1), 0.0, SIGXB, 0, XB )
      CALL RANNUM( 2, SEED(2), 0.0, SIGYB, 0, YB )
C
      ROUND = 0
      TIME = 0.0
      DO 101 I = 1, 5
        FIRST(I) = 1
        SCORE(I) = 0
        DO 102 J = 1, N(I)
          NEXT(I, J) = NEXTMATRIX(I, J)
102      CONTINUE
101 CONTINUE
C
100 CONTINUE
      ROUND = ROUND + 1
      TIME = TIME + ROUND / NPLAT / RATE
      CALL RANNUM( 2, SEED(3), 0.0, SIGXP, 0, XP )
      CALL RANNUM( 2, SEED(4), 0.0, SIGYP, 0, YP )
      XH = XB + XP
      YH = YB + YP
      DO 300 I = 1, 5
        IF ( N(I) .GT. 0 ) THEN
          ALT = AL0 + (AL(I) - AL0) * EXP(-GAMMA(I) * TIME)
          PK1 = 1. - ( 1. - ALT / (3.14159 * AP * BP) ) ** NBOM
150      CONTINUE
          IF ( FIRST(I) .GT. 0 ) THEN
            FST = .FALSE.

```

```

C      J = FIRST(I)
C      WRITE(3,*) 'FROM SALVO 1 ROUND=',ROUND,' J=',J
C      IF((((XH-X(I,J))/AP)**2+((YH-Y(I,J))/BP)**2).LT.1.)THEN
C          CALL RANNUM( 1, SEED(5), 0.0, 1.0, 0, RAN )
C          IF ( RAN .LT. PK1 ) THEN
C              FIRST(I) = NEXT(I,J)
C              SCORE(I) = SCORE(I) + 1
C              FST = .TRUE.
C          ENDIF
C      ENDIF
C      IF ( FST ) GO TO 150
C      PNT = FIRST(I)
C
C 200
C
C 200      IF ( NEXT(I, J) .GT. 0 ) THEN
C          J = NEXT(I,J)
C          IF((((XH-X(I,J))/AP)**2+((YH-Y(I,J))/BP)**2).LT.1.)THEN
C              CALL RANNUM( 1, SEED(5), 0.0, 1.0, 0, RAN )
C              IF ( RAN .LT. PK1 ) THEN
C                  NEXT(I,PNT) = NEXT(I,J)
C                  SCORE(I) = SCORE(I) + 1
C              ELSE
C                  PNT = J
C              ENDIF
C          ELSE
C              PNT = J
C          ENDIF
C          GO TO 200
C      ENDIF
C  ENDIF
C  ENDIF
C 300  CONTINUE
C
C
C      IF ( ROUND .LT. NSALVO ) GO TO 100
C
C      RETURN
C      END

```

=====

INCLUDE FILE

C400SYST DEF

C

C

```

      REAL SIGXP, SIGYP, SIGXB, SIGYB, RATE, AP, BP, AL(5), GAMMA(5)
      REAL AL0
      INTEGER NBOM
      COMMON /SYSTEM/ SIGXP, SIGYP, SIGXB, SIGYB, RATE, AP, BP, AL,
& NBOM, GAMMA, AL0

```

C

C RATE...RATE OF FIRE OF ONE PLATFORM

C

CTARGET DEF

```

      INTEGER N(5), NPLAT

```

```
REAL X(5,100), Y(5,100), LTIME  
COMMON/TARGET/ X, Y, N, NPLAT, LTIME
```

C

```
CSEED DEF
```

C

```
INTEGER SEED(8)  
COMMON/SEED SET/ SEED
```

C

```

PROGRAM SMARTMAIN
C =====
C SIMULATION OF TARGET DAMAGE ASSESSMENT, SMART SUBMUNITION WAREHEADS
C =====
C
C THE PROGRAM READS SYSTEM AND TARGET DATA. IT CALLS FOR SMARTSALVO
C SUBROUTINE TO SIMULATE THE DAMAGE LEVEL CAUSED BY FIRING VARIABLE
C ROUNDS IN A SALVO.
C WHILE RECEIVING THE ONE SALVO RESULTS, THE PROGRAM CALLS FOR
C STATISTICS SUBROUTINE THAT CALCULATE CONSECUTIVELY, AVERAGE,
C STANDARD DEVIATIONS AND CONFIDENCE INTERVALS.
C THE PROGRAM STOPS WHEN THE CONFIDENCE INTERVAL FOR 95% CONFIDENCE
C IS REDUCED TO A FIXED RESOLUTION.
C SIMULATION OF 5 TARGET TYPES THAT ARE DEPLOYED IS THE SAME AREA
C CAN BE HANDLED SIMULTANEOUSLY.
C TYPICALLY ANY COMBINATION OF 5 CAN BE CHOSEN LIKE THE FOLLOWING:
C TANK, APC, SELF-PROPELLED ARTILLERY GUN, SOFT VEHICLE.
C
C TD(I)...NUMBER OF TARGET TYPE I ELEMENTS THAT WERE DESTROYED.
C RESOL...RESOLUTION
C
C -----
C$INCLUDE: 'CTARGET.DEF'
C$INCLUDE: 'CSEED.DEF'
C$INCLUDE: 'SMARTSYS.DEF'
C$INCLUDE: 'SEARCH.DEF'
C @@@
C      INCLUDE 'CTARGET DEF'
C      INCLUDE 'CSEED DEF'
C      INCLUDE 'SMARTSS DEF'
C      INCLUDE 'SEARCH DEF'
C
C      INTEGER I, J, COUNT, TD(5)
C      INTEGER MINSALVO, MAXSALVO, INTERVAL, NSALVO
C      REAL TDAVG(5), TDSTD(5), RESOL(5), CONFINT, TLEX, TLEY
C      LOGICAL DONE
C      CHARACTER*8 TTYPE(5)
C
C      OPEN ( 1, FILE='SMARTTAR.DTA', STATUS='OLD')
C      OPEN ( 2, FILE='SMARTSYS.DTA', STATUS='NEW')
C      OPEN ( 3, FILE='SYSTEM.OUT', STATUS='OLD')
C      OPEN ( 4, FILE='SEED.DTA', STATUS='OLD' )
C @@@
C      OPEN ( 1, FILE='/TARGET7A DATA', STATUS='OLD')
C      OPEN ( 2, FILE='/SMARTSS DATA', STATUS='OLD')
C      OPEN ( 3, FILE='/CSYSTEM OUT', STATUS='OLD')
C      OPEN ( 4, FILE='/CSEED DATA', STATUS='OLD' )
C      OPEN ( 5, FILE='/SMARTMN LIST', STATUS='OLD' )
C
C      READ ( 2, *) SIGXP, SIGYP, SIGXB, SIGYB, SIGMAR, DIST, RSEARCH, R1, R2
C      READ ( 2, *) (PRH1(I), I=1, 5), (PRH2(I), I=1, 5), (PRH3(I), I=1, 5)
C      READ ( 2, *) (PRK1(I), I=1, 5), (PRK2(I), I=1, 5), (PRK3(I), I=1, 5)
C      READ ( 2, *) NPLAT, MINSALVO, MAXSALVO, INTERVAL, NSUB
C      READ ( 2, *) NAPX, NAPPY, DX, DY, TLEX, TLEY
C      READ ( 4, *) ( SEED(I), I=1, 8)
C

```

```

DATA RESOL / .1, .1, .1, .1, .01 /
C
SIGXB = SQRT(SIGXB**2 + TLEX**2)
SIGYB = SQRT(SIGYB**2 + TLEY**2)
C
DO 100 I=1, 5
  READ (1, *) N(I) , TTYPE(I)
  DO 100 J=1, N(I)
    READ (1, *) X(I,J), Y(I,J)
100  CONTINUE
C
WRITE (5, 40) SIGXB, SIGYB, NAPX, DX, TLEX, TLEY
C
DO 200 NSALVO = MINSALVO, MAXSALVO, INTERVAL
  COUNT = 0
  DO 201 I=1, 5
    TD(I) = 0
    TDAVG(I) = 0.0
201  CONTINUE
C
C
300  CONTINUE
C
  PRINT*, 'FROM MAIN COUNT=',COUNT, 'AP=',AP, 'BP=',BP
  DONE = .TRUE.
  CALL SMARTSALVO ( NSALVO, TD )
  DO 350 I = 1, 5
    IF ( N(I) .GT. 0 ) THEN
      CALL STATISTICS ( COUNT, TD(I), TDAVG(I), TDSTD(I) )
      IF (CONFINT(COUNT,TDSTD(I)).GT.RESOL(I))DONE =.FALSE.
      IF ( COUNT .LT. 10) DONE = .FALSE.
    ENDIF
350  CONTINUE
    COUNT = COUNT + 1
    IF ( .NOT. DONE ) GO TO 300
C
C
  WRITE (3, *)
  WRITE (3, *) ' SALVO=',NSALVO , ' REPEAT=',COUNT
  WRITE (3 ,10) ( TTYPE(I), TDAVG(I), I = 1, 5 )
  WRITE (3 ,20) ( TTYPE(I), TDAVG(I)/(N(I)+.001), I = 1, 5)
  WRITE (5 ,30) NSALVO,((TDAVG(I)/(N(I)+.001))*100, I = 1, 5)
200 CONTINUE
C
C
10  FORMAT (/ ,5(1X,A7,'=',F4.1) )
20  FORMAT ( 5(1X,A7,'=',F4.3) )
30  FORMAT ( 1X,I4,5(1X,F4.1) )
40  FORMAT ( ' SIGXB=',F7.2, ' SIGYB=',F7.2, ' NAPX=',I2, ' DX=',F6.1,
& ' TLEX=',F6.2, ' TLEY=',F6.2 )
  STOP
  END

```

```

SUBROUTINE SMARTSALVO( NSALVO, SCORE )
C
C-----
C THIS SUBROUTINE SIMULATES TARGET DAMAGE LEVEL AFTER FIRING A SALVO
C OF SMART WARHEAD ROUNDS.
C-----
C
C THE SUBROUTINE ACCEPTS THE TARGET ELEMENTS, LISTED IN X Y LOCATION
C ARRAYS. SAMPLES A BIAS ERROR. SAMPLES PRECISION ERROR. SAMPLE
C SUBMUNITION DISPERSION. SEARCHES FOR A TARGET ELEMENTS INSIDE THE
C THE SUBMUNITION SEARCHING CIRCLE. IF FOUND, IT IS RECORDED IN A
C DETECTED LIST. AMONG THE POTENTIALLY DETECTED TARGETS, ONE KILLED
C TARGET, PER ONE SUBMUNITION IS CHOSEN, IN ORDER OF THE FARER FROM THE
C SEARCHING CENTER, THE FIRST TO BE SAMPLED. COUNT NUMBER OF KILLED
C TARGETS. WHEN SALVO PREDETERMINED ROUNDS IS COMPLETED, RETURNS.
C
C-----
C
C$INCLUDE: 'CTARGET.DEF'
C$INCLUDE: 'CSEED.DEF'
C$INCLUDE: 'SMARTSS.DEF'
C @@@
      INCLUDE 'CTARGET DEF'
      INCLUDE 'CSEED DEF'
      INCLUDE 'SMARTSS DEF'
C @@@
      INTEGER ROUND, I, J, L, K, SCORE(5), II(500), JJ(500)
      INTEGER NSALVO, SUB(500), ISUB, PNT, IPNT, ND
      REAL XB, YB, XP, YP, THETA, RAN, XCS, YCS, RR(500), SPLITX
      REAL XX(5,100), YY(5,100), RMAX, DISTR, RANGE, PH1, PK1, SPLITY
C
      CALL RANNUM( 2, SEED(1), 0.0, SIGXB, 0, XB )
      CALL RANNUM( 2, SEED(2), 0.0, SIGYB, 0, YB )
C
      IF ( NAPX .GT.1 ) XB = XB + SPLITX(ROUND, NSALVO, NAPX, DX)
      IF ( NAPY .GT.1 ) YB = YB + SPLITY(ROUND, NSALVO, NAPY, DY)
C
      ROUND = 0
      DO 101 I = 1, 5
        SCORE(I) = 0
        DO 102 J = 1, N(I)
          XX(I, J) = X(I, J)
          YY(I, J) = Y(I, J)
102      CONTINUE
101 CONTINUE
C
100 CONTINUE
C      PRINT*, 'I AM IN THE SALVO LOOP ,ROUND=',ROUND,(N(I),I=1,5)
      ROUND = ROUND + 1
      CALL RANNUM( 2, SEED(3), 0.0, SIGXP, 0, XP )
      CALL RANNUM( 2, SEED(4), 0.0, SIGYP, 0, YP )
      PNT = 1
C
      DO 200 ISUB = 1, NSUB
        CALL RANNUM( 2, SEED(4), DIST, SIGMAR, 0, DISTR )
        CALL RANNUM( 1, SEED(5), 0.0, 6.28319, 0, THETA )

```



```

C      XCS = XB + XP + DISTR*COS(THETA)
      YCS = YB + YP + DISTR*SIN(THETA)
C      PRINT*, 'XCS=',XCS,'YCS=',YCS
C
      DO 300 I = 1, 5
        IF ( N(I) .GT. 0 ) THEN
          DO 400 J = 1, N(I)
            RANGE = SQRT( (XCS-XX(I,J))**2+(YCS-YY(I,J))**2 )
            IF ( RANGE .LT. RSEARCH ) THEN
              II(PNT) = I
              JJ(PNT) = J
              RR(PNT) = RANGE
              SUB(PNT) = ISUB
              PNT = PNT + 1
            ENDIF
          400      CONTINUE
        ENDIF
      300      CONTINUE
      200      CONTINUE
C
C      700      CONTINUE
      RMAX = 0.0
      DO 500 L = 1, PNT - 1
        IF ( SUB(L) .GT. 0 ) THEN
          IF ( RR(L) .GT. RMAX ) THEN
            RMAX = RR(L)
            IPNT = L
          ENDIF
        ENDIF
      500      CONTINUE
C
C      WRITE(3, 555) ( II(LL),JJ(LL),RR(LL),SUB(LL) ,LL=1,PNT-1)
C      555      FORMAT (I4,I4,F6.2,I3)
C      WRITE(3,*) 'IPNT=',IPNT,'PNT=',PNT,'RMAX=',RMAX,'ROUND=',ROUND
C      WRITE(3,*) 'IPNT=',IPNT,'PNT=',PNT,'RMAX=',RMAX,'ROUND=',ROUND
C
C      IF ( RMAX .LT. 0.1 ) GO TO 800
C
C      CALL RANNUM( 1, SEED(6), 0.0, 1.0, 0, RAN )
      IF ( RAN .LT. PH1(II(IPNT),RMAX) ) THEN
        ND = SUB(IPNT)
        DO 600 K = 1, (PNT - 1)
          IF ( SUB(K) .EQ. ND ) SUB(K) = 0
        600      CONTINUE
C
C      CALL RANNUM( 1, SEED(7), 0.0, 1.0, 0, RAN )
      IF ( RAN .LT. PK1(II(IPNT),RMAX) ) THEN
C      .....IN CASE OF A KILLED TARGET CAN BE HIT AGAIN
C      IF(II(K).EQ.II(IPNT).AND.JJ(K).EQ.JJ(IPNT).AND.
C      &      XX(II(K)).EQ. 1000000 ) )
C      .....MUST BE PUT AS NEGATIVE CONDITION
        SCORE(II(IPNT)) = SCORE(II(IPNT)) + 1
        XX(II(IPNT),JJ(IPNT)) = 1000000.

```

```

        DO 650 K = 1, (PNT - 1)
          IF (II(K).EQ.II(IPNT).AND.JJ(K).EQ.JJ(IPNT)) RR(K)=-1.
650      CONTINUE
        ENDIF
      ENDIF
      RR(IPNT) = -1.
      GO TO 700
C
800  CONTINUE
C
      IF ( ROUND .LT. NSALVO ) GO TO 100
C
C      PRINT*, (SCORE(I), I=1,5)
C      RETURN
C      END
C =====
      REAL FUNCTION PH1(I, R)
C =====
C THIS FUNCTION DETERMINES THE HIT PROBABILITY GIVEN EXSISTANCE
C OF TAGET INSIDE THE SUBMUNITION SEARCHING CIRCLE.
C =====
      INTEGER I
      REAL R
C$INCLUDE: 'SEARCH.DEF'
      INCLUDE 'SEARCH DEF'
      IF ( R .LT. R1 ) THEN
        PH1 = PRH1(I)
      ELSEIF ( R .LT. R2 ) THEN
        PH1= PRH2(I)
      ELSE
        PH1 = PRH3(I)
      ENDIF
      RETURN
      END
C =====
      REAL FUNCTION PK1(I, R)
C =====
C THIS FUNCTION DETERMINES THE KILL PROBABILITY GIVEN EXSISTANCE
C OF TAGET INSIDE THE SUBMUNITION SEARCHING CIRCLE.
C =====
      INTEGER I
      REAL R
C$INCLUDE: 'SEARCH.DEF'
      INCLUDE 'SEARCH DEF'
      IF ( R .LT. R1 ) THEN
        PK1 = PRK1(I)
      ELSEIF ( R .LT. R2 ) THEN
        PK1= PRK2(I)
      ELSE
        PK1 = PRK3(I)
      ENDIF
      RETURN
      END
=====

```

INCLUDE FILES

CTARGET DEF

C

INTEGER N(5), NPLAT
REAL X(5,100), Y(5,100), LTIME
COMMON/TARGET/ X, Y, N, NPLAT, LTIME

C

CSEED DEF

C

INTEGER SEED(8)
COMMON/SEED SET/ SEED

C

SMARTSS DEF

C

REAL SIGXP, SIGYP, SIGXB, SIGYB, RATE, RSEARCH, SIGMAR, DIST
REAL DX, DY
INTEGER NSUB, NAPX, NAPI
COMMON /SYSTEM/ SIGXP, SIGYP, SIGXB, SIGYB, RATE, RSEARCH, NSUB,
& SIGMAR, DIST, NAPX, NAPI, DX,DY

C

C

SEARCH DEF

C

REAL R1, R2, PRH1(5), PRH2(5), PRH3(5), PRK1(5), PRK2(5), PRK3(3)
COMMON /SEARCHCIRCLE/ R1, R2, PRH1, PRH2, PRH3, PRK1, PRK2, PRK3

C

```

      REAL FUNCTION SPLITX(ROUND, NSALVO, NAPX, DX)
C *****
C THIS FUNCTION DEVIATES THE AIMPOINT FOR LARGE TARGET
C
      INTEGER ROUND, NSALVO, NAPX, N, M
      REAL DX
      IF (NSALVO .LT. NAPX) THEN
        SPLITX = 0.
        GO TO 200
      ENDIF
      IF( INT( REAL(NAPX)/2. ) .LT. ( ( REAL(NAPX)/2. ) - 0.1 ) ) THEN
        M=1
        N=0
100    CONTINUE
        IF (ROUND .LT. ((REAL(M)/REAL(NAPX) )*NSALVO + 0.7)) THEN
          SPLITX = 2.*DX/(NAPX-1)*N*((-1)**M)
          GO TO 200
        ENDIF
        M = M + 1
        N = INT( REAL(M) / 2. )
        GO TO 100
      ELSE
        M=1
        N=0
120    CONTINUE
        IF ( ROUND .LT. (( REAL(M)/REAL(NAPX) )*NSALVO + 0.6)) THEN
          SPLITX = 2.*DX/REAL(NAPX-1)*( N+.5 )*((-1)**(M+1))
          GO TO 200
        ENDIF
        M = M + 1
        N = INT( REAL(M-1) / 2. )
        GO TO 120
      ENDIF
200    CONTINUE
      RETURN
      END

C
C
      REAL FUNCTION SPLITX(ROUND, NSALVO, NPY, DY)
C *****
C THIS FUNCTION DEVIATES THE AIMPOINT FOR DEEP TARGET
C
      INTEGER ROUND, NSALVO, NPY, N, M
      REAL DY
      IF (NSALVO .LT. NPY) THEN
        SPLITX = 0.
        GO TO 200
      ENDIF
      IF( INT( REAL(NPY)/2. ) .LT. ( ( REAL(NPY)/2. ) - 0.1 ) ) THEN
        M=1
        N=0
100    CONTINUE
        IF ( ROUND .LT. (( REAL(M)/REAL(NPY) )*NSALVO + 0.6)) THEN
          SPLITX = 2.*DY/(NPY-1)*N*((-1)**M)
          GO TO 200
        ENDIF

```

```

        M = M + 1
        N = INT( REAL(M) / 2. )
        GO TO 100
ELSE
    M=1
    N=0
120    CONTINUE
        IF ( ROUND .LT. (( REAL(M)/REAL(NAPY) ) * NSALVO + 0.7) ) THEN
            SPLIT = 2.*DY/REAL(NAPY-1)*( N+.5 )*((-1)**(M+1))
            GO TO 200
        ENDIF
        M = M + 1
        N = INT( REAL(M-1) / 2. )
        GO TO 120
    ENDIF
200    CONTINUE
    RETURN
END

```

```

C*****
REAL FUNCTION CONFINT (REP, STD)
C-----
  INTEGER REP
  REAL STD
  IF (REP.GT.2) THEN
    CONFINT=4.* STD/SQRT (REAL (REP-1))
  ELSE
    CONFINT = 4.
  ENDIF
  RETURN
END

C*****
SUBROUTINE STATISTICS (REPEAT, NEWX, AVGX, STDY)
C-----
C THIS SUBROUTINE CALCULATES THE AVERAGE OF A CURRENT
C INCREMENTED SAMPLE, AND CALLS FOR SUBROUTINE STDEV
C TO CALCULATE THE STANDARD DEVIATION.
C-----
  INTEGER REPEAT, NEWX
  REAL AVGX, STDY, XAVOLD
  XAVOLD=AVGX
C  WRITE(*,*) 'I AM IN STATISTICS REPEAT=', REPEAT
  XAVOLD=AVGX
  AVGX=(REPEAT*AVGX+NEWX)/REAL (REPEAT+1)
  CALL STDEV (REPEAT, NEWX, AVGX, STDY, XAVOLD)
  RETURN
END

C*****
SUBROUTINE STDEV (REPEAT, NEWX, AVGX, STDY, XAVOLD)
C-----
  INTEGER REPEAT, NEWX
  REAL AVGX, STDY, XAVOLD, RP
  IF (REPEAT .EQ.0) THEN
    STDY=0.0
    RETURN
  ELSE
    RP=REAL (REPEAT)
    STDY=SQRT ((RP-1.)/RP*STDY**2+XAVOLD**2+NEWX**2/RP-(RP+1.)/RP
    & *AVGX**2)
  ENDIF
  RETURN
END

```

```

C
C SUBROUTINE RANNUM(DISTN, SEED, RPARM1, RPARM2, IPARM, X)
C
C THIS SUBROUTINE PROVIDES AN INTERFACE WITH THE LLRANDOMII
C ROUTINES PROVIDED IN THE NONIMSL LIBRARY. THE PARAMETER
C REQUIREMENTS AND CALLING PROCEDURES ARE AS FOLLOWS:
C
C DISTN = DISTRIBUTION TYPE YOU WANT TO SELECT
C AN INTEGER BETWEEN 1 AND 7
C SEED = THE RANDOM NUMBER SEED YOU WISH TO USE
C RPARM1, RPARM2, AND IPARM ARE REAL AND INTEGER PARAMETERS
C PASSED TO THE ROUTINE WITH MEANINGS WHICH VARY WITH THE TYPE OF
C DISTRIBUTION YOU DESIRE
C NOTE: IPARM IS CURRENTLY NOT BEING USED.
C X = THE RETURNED RANDOM NUMBER, IT IS ALWAYS REAL
C
C DISTRIBUTION NUMBERS AND THE ASSOCIATED PARM DEFINITIONS
C
C 1--UNIFORM ON THE INTERVAL RPARM1 TO RPARM2
C 2--NORMAL WITH MEAN RPARM1 AND STD DEV RPARM2
C 3--EXPONENTIAL WITH RATE RPARM1
C 4--COUCHY WITH A = RPARM1 AND B = RPARM2
C 5--GAMMA WITH SHAPE RPARM2 AND RATE RPARM1
C 6--POISSON WITH RATE RPARM1
C 7--GEOMETRIC WITH P = RPARM1
C
C NOTE TO NEW USERS: THIS FUNCTION NOW HAS TWO CALLS TO LLRAN
C FOR EACH TYPE OF VARIATE, ONE COMPATABLE WITH THE MAINFRAME
C LLRANDOMII, AND ONE COMPATABLE WITH RNDG.LIB FOR THE PC
C THE PC VERSIONS ALL END IN 'PC'
C ONE IS ALWAYS COMMENTED OUT.
C
C VERY IMPORTANT: IF YOU ARE USING THE LLRANDOMII CALLS, MAKE
C SURE TO COMMENT OUT THE STATEMENT
C SEED = INT(PCSEED)
C
C REAL RPARM1, RPARM2, X
C INTEGER DISTN, SEED, IPARM, N
C DOUBLE PRECISION PCSEED
C REAL TEMP, VARIAT(1)
C
C TRANSLATION FOR PCs
C
C PCSEED = DFLOAT(SEED)
C N = 1
C
C IF (DISTN.LE.0.OR.DISTN.GT.8) THEN
C WRITE(10, *) 'ILLEGAL CALL TO RANNUM, BAD DISTN'
C STOP
C ENDIF
C
C WRITE(10, *)
C WRITE(10, *) '!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!'
C WRITE(*, *) 'FROM RANNUM'
C WRITE(*, *) 'DISTRIBUTION NUMBER = ', DISTN
C WRITE(*, *) 'SEED = ', SEED

```

```

C      WRITE(* , *) 'PCSEED = ', PCSEED
C      WRITE(* , *) 'RPARMS ARE ', RPARM1, ' ', RPARM2
C
C      GOTO (10, 20, 30, 40, 50, 60, 70), DISTN
C
C      GENERATE A UNIFORM BETWEEN RPARM1 AND RPARM2
10     CONTINUE
C
C      IF (RPARM1 - RPARM2.EQ.0) THEN
C          WRITE(10, *) 'ILLEGAL EQUAL RPARMS IN RANNUM'
C          STOP
C      ENDIF
C      IF (RPARM1.GT.RPARM2) THEN
C          TEMP = RPARM1
C          RPARM1 = RPARM2
C          RPARM2 = TEMP
C      ENDIF
C
C      CALL LRNDPC(PCSEED, VARIAT, N)
C      CALL LRND(SEED, VARIAT, 1, 1, 0)
C
C      VARIAT(1) = RPARM1 + (RPARM2 - RPARM1) * VARIAT(1)
C      GOTO 99
C
C      GENERATE A NORMAL WITH MEAN RPARM1 AND STDDEV RPARM2
20     CONTINUE
C      CALL LNORPC(PCSEED, VARIAT, N)
C      CALL LNORM(SEED, VARIAT, 1, 1, 0)
C      VARIAT(1) = (VARIAT(1) * RPARM2) + RPARM1
C      GOTO 99
C
C      GENERATE AN EXPONENTIAL WITH RATE (1/MEAN) RPARM1
30     CONTINUE
C      IF (RPARM1.EQ.0) THEN
C          WRITE(10, *) 'ILLEGAL ZERO RATE IN RANNUM'
C          STOP
C      ENDIF
C      CALL LGAMPC(PCSEED, VARIAT, N, 1.0)
C      CALL LEXPN(SEED, VARIAT, 1, 1, 0)
C      VARIAT(1) = VARIAT(1) / RPARM1
C      GOTO 99
C
C      GENERATE A COUCHY WITH A = RPARM1 AND B = RPARM2
40     CONTINUE
C      IF (RPARM2.LE.0) THEN
C          WRITE(10, *) 'ILLEGAL COUCHY SPREAD IN RANNUM, B = ', RPARM2
C          STOP
C      ENDIF
C      CALL LCHYPC(PCSEED, VARIAT, N)
C      CALL LCCHY(SEED, VARIAT, 1, 1, 0)
C      VARIAT(1) = (VARIAT(1) * RPARM2) + RPARM1
C      GOTO 99
C
50     CONTINUE
C      IF (RPARM1.LE.0) THEN
C          WRITE(10, *) 'ILLEGAL NONPOSITIVE GAMMA RATE IN RANNUM'

```



```

        STOP
    ENDIF
    IF (RPARM2.LE.0) THEN
C        WRITE(10, *) 'ILLEGAL SHAPE PARAMETER IN RANNUM'
        STOP
    ENDIF
C    CALL LGAMPC(PCSEED, VARIAT, N, RPARM2)
    CALL LGAMA(SEED, VARIAT, 1, 1, 0, RPARM2)
    VARIAT(1) = VARIAT(1) * (1.0 / RPARM1)
    GOTO 99

60    CONTINUE
    IF (RPARM1.LE.0) THEN
C        WRITE(10, *) 'ILLEGAL POISSON RATE IN RANNUM'
        STOP
    ENDIF
C    CALL LPOIPC(PCSEED, VARIAT, N, RPARM1)
    CALL LPOIS(SEED, VARIAT, 1, 1, 0, RPARM1)
    GOTO 99

70    CONTINUE
    IF (RPARM1.LE.0) THEN
C        WRITE(*, *) 'RETURNING ', X
C        WRITE(10, *) 'oooooooooooooooooooooooooooooooooooooooooooo'
C        WRITE(10, *)
    RETURN
    END

```

LIST OF REFERENCES

1. Grubbs, Frank E., "Expected Target Damage for a Salvo of Rounds With Elliptical Normal Delivery and Damage Functions," *Operational Research*, vol. 16, 1968.
2. Hess, Carl Holmes, *Engineering Industrial Effectiveness Of Sequences In Unadjusted Artillery Fire*, Ph.D. dissertation, The University of Michigan, 1968.
3. Eckler, A. Ross, and Burr, Stefan A., "Mathematical Models Of Target Coverage and Missile Allocation," *Military Operations Research Society*, 1972.
4. Massey, H. G., and Shaver, R. D., *Mathematics Of Strategic Indirect Bomb Damage Assessment for Point Target*, United States Air Force Project Rand, 1973.
5. Antonioti, Joseph C., "Precision-guided munitions," *International Defense Review*, vol. 19, no. 9 (1986), pp. 1269-1276.

INITIAL DISTRIBUTION LIST

	<u>No. Copies</u>
1. Defense Technical Information Center Cameron Station Alexandria, VA 22304-6145	2
2. Library, Code 0142 Naval Postgraduate School Monterey, CA 93943-5002	2
3. Professor D. C. Boger, Code OR/Bo Naval Postgraduate School Monterey, CA 93943-5002	2
4. Professor S. H. Parry, Code OR/Py Naval Postgraduate School Monterey, CA 93943-5002	2
5. Giora Arbel IMI Ltd. Rocket Systems Division P. O. Box 1044 Ramat-Hasharon 47100 Israel	2